IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SYMBOL TECHNOLOGIES, INC., a Delaware corporation, and WIRELESS VALLEY COMMUNICATIONS, INC., a Delaware corporation,	)	C.A. No. 07-519-JJF
Plaintiffs/Counterclaim Defendants,	)	
v.	)	**JURY DEMANDED**
ARUBA NETWORKS, INC., a Delaware corporation,	)	
Defendant/Counterclaim Plaintiff.	)	

DECLARATION OF ARUN CHANDRA IN SUPPORT OF SYMBOL TECHNOLOGIES, INC.'S AND WIRELESS VALLEY COMMUNICATIONS, INC.'S OPPOSITION TO DEFENDANT ARUBA NETWORKS, INC.'S MOTION TO STAY PENDING RE-EXAMINATION OF THE PATENTS-IN-SUIT

VOLUME 1 OF 2

Exhibits 1-11

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Dated April 21, 2008
861149 / 32106

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SYMBOL TECHNOLOGIES, INC., a Delaware corporation, and WIRELESS VALLEY COMMUNICATIONS, INC., a Delaware corporation,	)	C.A. No. 07-519-JJF
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I, Arun Chandra, declare as follows:

1. I am an attorney in the State of New York and an associate in the law firm of Hogan & Hartson, LLP, 875 Third Ave., New York, New York, 10022. This declaration is being submitted in support of Plaintiffs' Symbol Technologies, Inc. and Wireless Valley Communications, Inc. (hereinafter "Plaintiffs") Opposition to Defendant Aruba Networks, Inc.'s (hereinafter "Aruba") Motion to Stay Pending Re-Examination of the Patents in Suit in the above identified matter. I make this declaration as of my own personal knowledge and/or my review of the records in this action.

2. Attached here to as Exhibit 1 is a true and correct copy of the August 27, 2007 Complaint, filed in this action.

3. Attached hereto as Exhibit 2 is a true and correct copy of the October 17, 2007 Answer and Counterclaims, filed by Aruba in this action.

4. Attached hereto as Exhibit 3 is a true and correct copy of a press release describing the National Medal of Technology received by Symbol in 1999.

5. Attached hereto as Exhibit 4 is a true and correct copy of a press release describing the National Medal of Technology received by Symbol in 1999.

6. Attached hereto as Exhibit 5 is a true and correct copy of a press release describing the National Medal of Technology received by Motorola, Inc. in 2005.

7. Attached hereto as Exhibit 6 is a true and correct copy of the February 22, 2008 e-mail from Plaintiffs' counsel to Aruba's counsel, seeking agreement on a proposed scheduling order in this action.

8. Attached hereto as Exhibit 7 is a true and correct copy of the February 26, 2008 e-mail from Plaintiffs' counsel to Aruba's counsel, seeking agreement on a proposed scheduling order in this action.

9. Attached hereto as Exhibit 8 is a true and correct copy of the March 5, 2008 letter from Plaintiffs' counsel to the Court, submitting Plaintiffs' proposed scheduling order.

10. Attached hereto as Exhibit 9 is a true and correct copy of the March 7, 2008 letter from Aruba's counsel to the Court, stating Aruba's intent to seek a stay.

11. Attached hereto as Exhibit 10 is a true and correct copy of selected excerpts of the prosecution history for the '922 patent.

12. Attached hereto as Exhibit 11 is a true and correct copy of U.S. Patent No. 6,414,950.

13. Attached hereto as Exhibit 12 is a true and correct copy of U.S. Patent No. 6,665,536.

14. Attached hereto as Exhibit 13 is a true and correct copy of U.S. Patent No. 6,421,714.

15. Attached hereto as Exhibit 14 is a true and correct copy of U.S. Patent No. 6,493,679.

16. Attached hereto as Exhibit 15 is a true and correct copy of a datasheet for Aruba AP-70 Access Point.

17. Attached hereto as Exhibit 16 is a true and correct copy of a datasheet for Symbol's AP300 Access Port.

18. Attached hereto as Exhibit 17 is a true and correct copy of a datasheet for Aruba MC-2400 Mobility Controller.

19. Attached hereto as Exhibit 18 is a true and correct copy of a datasheet for Symbol's WS5100 Wireless Switch.

20. Attached hereto as Exhibit 19 is a true and correct copy of a datasheet for Aruba Mobility Management System.

21. Attached hereto as Exhibit 20 is a true and correct copy of a datasheet for Wireless Valley's EnterprisePlanner.

22. Attached hereto as Exhibit 21 is a true and correct copy of a datasheet for Wireless Valley's LANPlanner.

23. Attached hereto as Exhibit 22 is a true and correct copy of Aruba's press release, entitled *Aruba Gains Market Share and Solidifies Position as the World's Second Largest Enterprise Wireless LAN Supplier* (Sept. 7, 2007), available at http://www.arubanetworks.com/company/news/release.php?id=33).

24. Attached hereto as Exhibit 23 is a true and correct copy of Peter Judge, *Enterprise Wi-Fi – the Market Shifts Again,* TechWorld (Sept. 21, 2007), available at http://techworld.com/mobility/features/ index.cfm?featureid=3674.

25. Attached hereto as Exhibit 24 is a true and correct copy of Bill Simpson, *IPO Analysis: Aruba Networks Doesn't Have Enough Under The Hood*, Seeking Alpha (April 3, 2007), available at http://seekingalpha.com/article/31416-ipo-analysis-aruba-networks-doesn-t-have-enough-under-the-hood.

26. Attached hereto as Exhibit 25 is a true and correct copy of the Goldman Sachs' recent research report on the Communications Technology sector.

27. Attached hereto as Exhibit 26 is a true and correct copy of the J.P. Morgan's recent research report on Aruba Networks, Inc.

28. Attached hereto as Exhibit 27 is a true and correct copy of the Jaywalk Consensus (an average of independent research providers) on Aruba Networks, Inc.

29. Attached hereto as Exhibit 28 is a true and correct copy of the PTO statistics regarding *inter partes* and *ex parte* re-examinations.

30. Attached hereto as Exhibit 29 is a true and correct copy of U.S. Patent No. 6,973,622.

I declare that the foregoing statements made by me are true. I am aware that if any of the foregoing statements made by me are willfully false, I am subject to punishment.

Dated: April 21, 2008

/s/ Arun Chandra
Arun Chandra

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CERTIFICATE OF SERVICE

I, Richard L. Horwitz, hereby certify that on April 21, 2008, the attached document was electronically filed with the Clerk of the Court using CM/ECF which will send notification to the registered attorney(s) of record that the document has been filed and is available for viewing and downloading.

I further certify that on April 21, 2008, I have Electronically Mailed the document to the following person(s):

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EXHIBIT 1

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SYMBOL TECHNOLOGIES, INC., a Delaware corporation, and WIRELESS VALLEY COMMUNICATIONS, INC., a Delaware corporation, Plaintiffs, v. ARUBA NETWORKS, INC., a Delaware corporation, Defendant.	)))))))))))))	C.A. No. _____________ **JURY DEMANDED**

COMPLAINT FOR PATENT INFRINGEMENT

Plaintiffs Symbol Technologies, Inc. ("Symbol") and Wireless Valley Communications, Inc. ("Wireless Valley") (collectively "Plaintiffs"), by their counsel, as and for their Complaint against Defendant Aruba Networks, Inc. ("Aruba"), allege as follows:

PARTIES

1. Symbol is a Delaware corporation having its principal place of business at One Motorola Plaza, Holtsville, New York 11742-1300. Symbol develops and markets innovative, high-performance products, including, *inter alia*, wireless local area networks ("WLANs") and their components, including wireless access points and wireless switches. Symbol is a wholly-owned subsidiary of Motorola Inc.

2. Wireless Valley is a Delaware corporation having its principal place of business at 4515 Seton Center Parkway, Suite 330, Austin, Texas 78759. Wireless Valley is a leading provider of software solutions for the design and management of WLANs. Wireless Valley is a wholly-owned subsidiary of Motorola, Inc.

3. Upon information and belief, Aruba is a Delaware corporation having its principal place of business at 1322 Crossman Ave., Sunnyvale, CA 94089-1113. Aruba maintains The Corporation Trust Company as its registered agent for the service of process in Delaware. Aruba designs, manufacturers, and sells in the United States wireless switches (which it calls mobility controllers), access points, management servers, and related software for use in connection with WLANs, as well as software for designing, planning, configuring, monitoring, managing, and optimizing WLANs.

JURISDICTION AND VENUE

4. This is an action arising under the patent laws of the United States, 35 U.S.C. §§ 101 *et seq*. This Court has subject matter jurisdiction pursuant to 35 U.S.C. § 271 *et seq*. and 28 U.S.C. §§ 1331 and 1338.

5. Venue is proper in this judicial district under 28 U.S.C. §§ 1391 and 1400.

6. This Court has personal jurisdiction over Aruba because Aruba is a Delaware corporation with an agent for service of process in Delaware. Upon information and belief, Aruba also places its infringing products in the stream of commerce, which stream is directed at this district.

THE PATENTS

7. Symbol is the owner by assignment of United States Letters Patent No. 7,173,922 ("the '922 Patent"), entitled "Multiple Wireless Local Area Networks Occupying Overlapping Physical Spaces." The '922 Patent duly and legally issued Feb. 6, 2007. A copy of the '922 Patent is attached to this Complaint as Exhibit A.

8. Symbol is the owner by assignment of United States Letters Patent No. 7,173,923 ("the '923 Patent"), entitled "Security In Multiple Wireless Local Area Networks." The '923 Patent duly and legally issued Feb. 6, 2007. A copy of the '923 Patent is attached to this Complaint as Exhibit B.

9. Symbol is the owner of all rights, title and interest in and to the '922 Patent and '923 Patent (collectively "the Symbol Patents") and is entitled to sue for past and future infringement of those patents.

10. Wireless Valley is the owner by assignment of United States Letters Patent No. 6,625,454 ("the '454 Patent"), entitled "Method and System for Designing or Deploying a Communications Network Which Considers Frequency Dependent Effects" The '454 Patent duly and legally issued Sept. 23, 2003. A copy of the '454 Patent is attached to this Complaint as Exhibit C.

11. Wireless Valley is the owner by assignment of United States Letters Patent No. 6,973,622 ("the '622 Patent"), entitled "System and Method for Design, Tracking, Measurement, Prediction and Optimization of Data Communications Networks." The '622 Patent duly and legally issued Dec. 6, 2005. A copy of the '622 Patent is attached to this Complaint as Exhibit D.

12. Wireless Valley is the owner of all rights, title and interest in and to the '454 Patent and '622 Patent (collectively "the Wireless Valley Patents") and is entitled to sue for past and future infringement of those patents.

FIRST CLAIM FOR RELIEF
(INFRINGEMENT OF THE '922 PATENT)

13. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

14. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '922 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '922 Patent.

15. Aruba has had actual and/or constructive notice and knowledge of the '922 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '922 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '922 Patent.

16. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement of the '922 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products that are covered by the '922 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '922 Patent.

17. On information and belief, Aruba's infringement of the'922 Patent is willful. The continued infringement of the '922 Patent by Aruba has damaged and will continue to damage Symbol.

18. The infringement of the '922 Patent by Aruba has caused and will continue to cause Symbol irreparable harm unless preliminarily and permanently enjoined by the Court. Symbol has no adequate remedy at law.

SECOND CLAIM FOR RELIEF
(INFRINGEMENT OF THE '923 PATENT)

19. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

20. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '923 Patent.

21. Aruba has had actual and/or constructive notice and knowledge of the '923 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '923 Patent.

22. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement of the '923 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products that are covered by the '923 Patent.

23. On information and belief, Aruba's infringement of the '923 Patent is willful. The continued infringement of the '923 Patent by Aruba has damaged and will continue to damage Symbol.

24. The infringement of the '923 Patent by Aruba has caused and will continue to cause Symbol irreparable harm unless preliminarily and permanently enjoined by the Court. Symbol has no adequate remedy at law.

THIRD CLAIM FOR RELIEF
(INFRINGEMENT OF THE '454 PATENT)

25. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

26. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '454 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '454 Patent.

27. Aruba has had actual and/or constructive notice and knowledge of the '454 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '454 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '454 Patent.

28. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement one or more claims of the '454 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products covered by the '454 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '454 Patent.

29. On information and belief, Aruba's infringement of the '454 Patent is willful. The continued infringement of the '454 Patent by Aruba has damaged and will continue to damage Wireless Valley.

30. The infringement of the '454 Patent by Aruba has caused and will continue to cause Wireless Valley irreparable harm unless preliminarily and permanently enjoined by the Court. Wireless Valley has no adequate remedy at law.

FOURTH CLAIM FOR RELIEF
(INFRINGEMENT OF THE '622 PATENT)

31. Plaintiffs repeat and reallege the allegations in paragraphs 1-12 as if fully set forth herein.

32. Aruba has imported into the United States, made, used, sold and/or offered for sale in the United States, products covered by the '622 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '622 Patent.

33. Aruba has had actual and/or constructive notice and knowledge of the '622 Patent. The filing of this Complaint also constitutes notice in accordance with 35 U.S.C. § 287. Despite such notice, Aruba continues to import, make, use, sell and/or offer for sale in the United States products covered by the '622 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '622 Patent.

34. Aruba has infringed and/or induced the infringement of and/or contributed to the infringement of one or more claims of the '622 Patent by importing, making, using, offering for sale, or selling in the United States, or by intending that others import, make, use, offer for sale, or sell in the United States, products that are covered by the '622 Patent and/or products that when used in accordance with their instructions practice the methods covered by the '622 Patent.

35. On information and belief, Aruba's infringement of the '622 Patent is willful. The continued infringement of the '622 Patent by Aruba has damaged and will continue to damage Wireless Valley.

36. The infringement of the '622 Patent by Aruba has caused and will continue to cause Wireless Valley irreparable harm unless preliminarily and permanently enjoined by the Court. Wireless Valley has no adequate remedy at law.

WHEREFORE, Symbol and Wireless Valley pray for a relief and judgment against Aruba as follows:

A. Adjudging that Aruba is infringing the Symbol Patents and the Wireless Valley Patents;

B. Adjudging that the infringement by Aruba of the Symbol Patents and the Wireless Valley Patents was willful, and that the continued infringement by Aruba of the Symbol Patents and Wireless Valley Patents is willful;

C. Entering an order preliminarily and permanently enjoining Aruba from any further acts of infringement of the Symbol Patents and the Wireless Valley Patents;

D. Awarding Wireless Valley damages in an amount adequate to compensate for the infringement by Aruba of the Wireless Valley Patents, but in no event less than a reasonable royalty under 35 U.S.C. § 284;

E. Entering an order trebling any and all damages awarded to Wireless Valley by reason of the willful infringement by Aruba of the Wireless Valley Patents, pursuant to 35 U.S.C. § 284;

F. Awarding Symbol damages in an amount adequate to compensate for the infringement by Aruba of the Symbol Patents, but in no event less than a reasonable royalty under 35 U.S.C. § 284;

G. Entering an order trebling any and all damages awarded to by reason of the willful infringement by Aruba of the Symbol Patents, pursuant to 35 U.S.C. § 284;

H. Entering an order awarding Symbol and Wireless Valley interest on the damages awarded and their costs pursuant to 35 U.S.C. § 284;

I. Declaring this an exceptional case and awarding Symbol and Wireless Valley their costs, expenses, and reasonable attorneys' fees pursuant to 35 U.S.C. § 285 and all other applicable statutes, rules, and common law; and

J. Awarding Symbol and Wireless Valley such other and further relief as the Court may deem just and proper.

JURY DEMAND

Symbol and Wireless Valley hereby demand trial by jury on all issues in its Complaint.

Respectfully submitted,

POTTER ANDERSON & CORROON LLP

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Date: August 27, 2007
809726 / 32106

EXHIBIT A

US007173922B2

(12) **United States Patent**
Beach

(10) **Patent No.:** **US 7,173,922 B2**
(45) **Date of Patent:** ***Feb. 6, 2007**

(54) **MULTIPLE WIRELESS LOCAL AREA NETWORKS OCCUPYING OVERLAPPING PHYSICAL SPACES**

(75) Inventor: **Robert Beach**, Los Altos, CA (US)

(73) Assignee: **Symbol Technologies, Inc.**, Holtsville, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 704 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/780,741**

(22) Filed: **Feb. 9, 2001**

(65) **Prior Publication Data**

US 2001/0055283 A1 Dec. 27, 2001

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/528,697, filed on Mar. 17, 2000.

(51) **Int. Cl.**

H04Q 7/24	(2006.01)
H04L 12/28	(2006.01)
H04L 12/56	(2006.01)

(52) **U.S. Cl.** **370/338**; 370/466; 370/401

(58) **Field of Classification Search** 370/338, 370/328, 333, 334, 339, 343, 400, 401, 491, 370/492, 465, 466, 469

See application file for complete search history.

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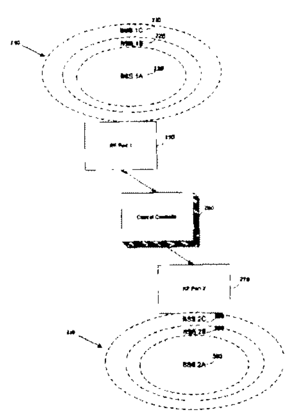
Primary Examiner—Chirag Shah
(74) *Attorney, Agent, or Firm*—Ingrassia Fisher & Lorenz, P.C.

(57) **ABSTRACT**

A wireless local area network is provided with simplified RF ports which are configured to provide lower level media access control functions. Higher level media access control functions are provided in a cell controller, which may service one or more RF ports that are capable operating with at least two wireless local area subnetworks occupying common physical space. Mobile units can also be configured with the higher level media access control functions being performed in a host processor.

45 Claims, 7 Drawing Sheets



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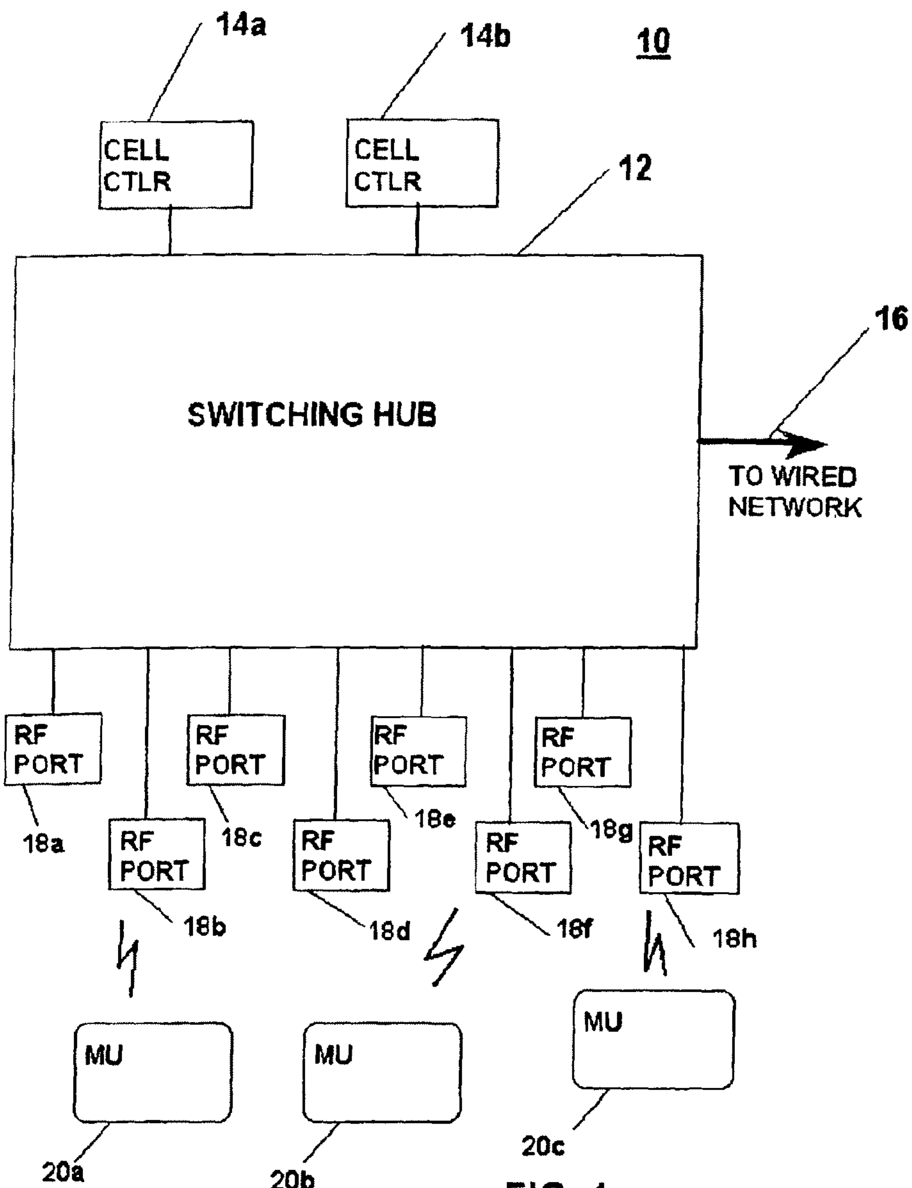

14a
14b
10
CELL CTLR
CELL CTLR
12
16
SWITCHING HUB
TO WIRED NETWORK
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
18a
18b
18c
18d
18e
18f
18g
18h
MU
MU
MU
20a
20b
20c

FIG. 1

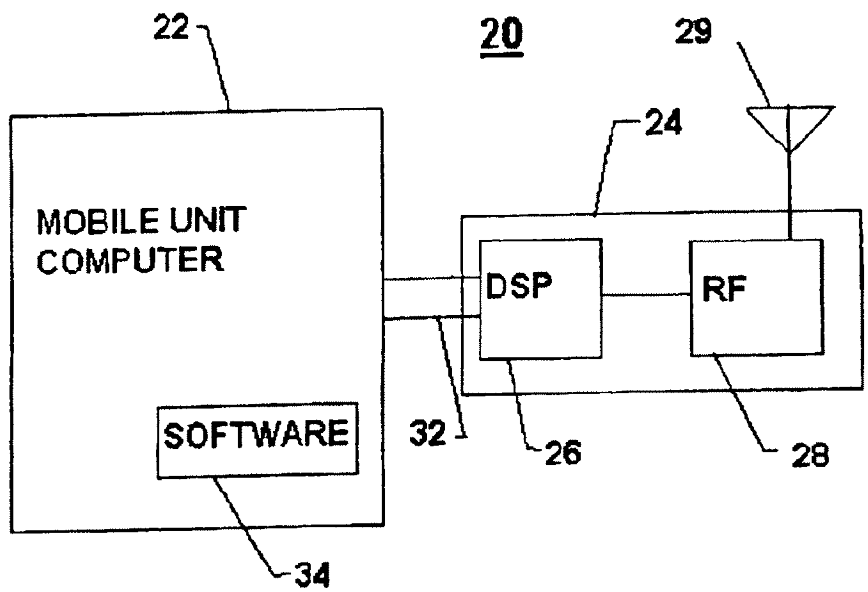


FIG. 2

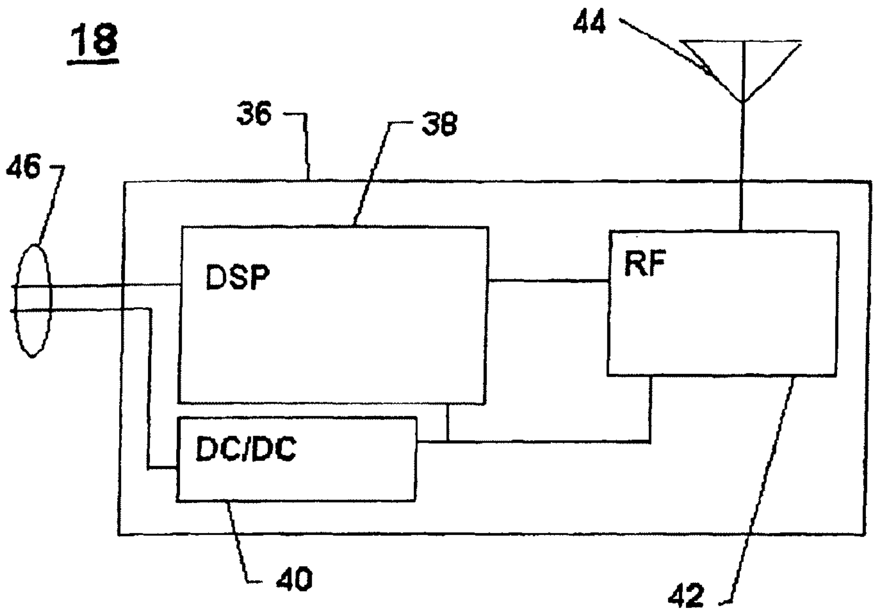


FIG.3

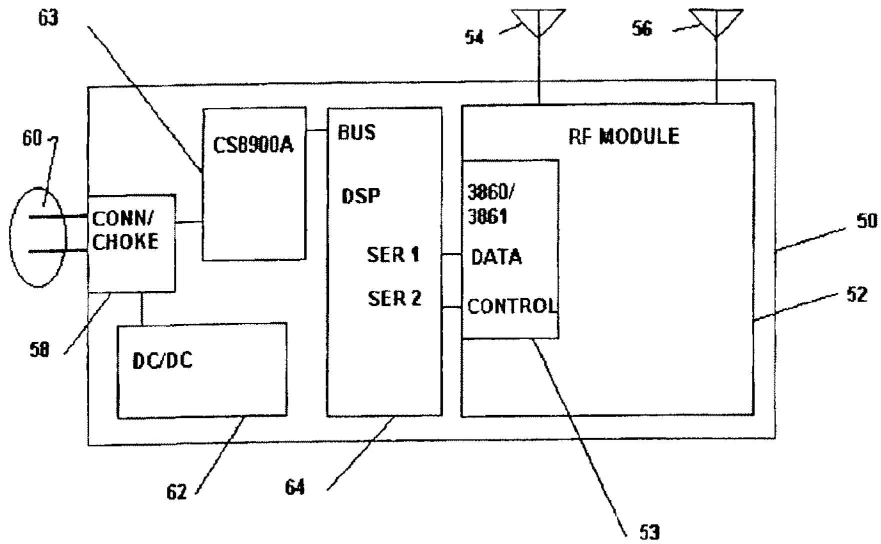

63
54
56
60
CS8900A
BUS
DSP
RF MODULE
3860/
3861
CONN/
CHOKE
SER 1
SER 2
DATA
CONTROL
50
52
58
DC/DC
62
64
53

FIG. 4

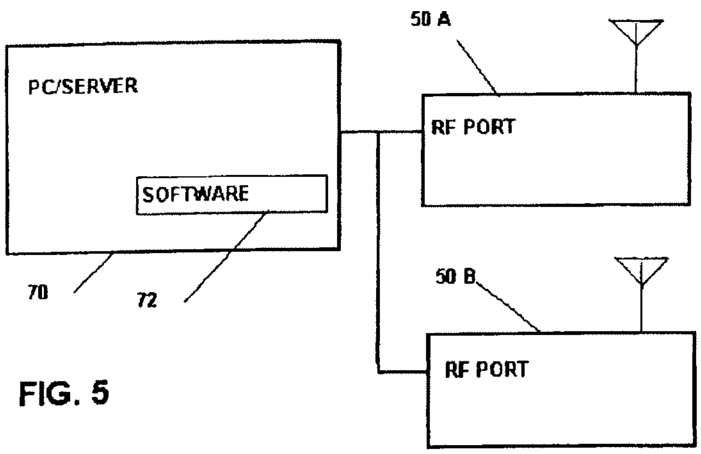

50 A
PC/SERVER
RF PORT
SOFTWARE
70
72
50 B
RF PORT

FIG. 5

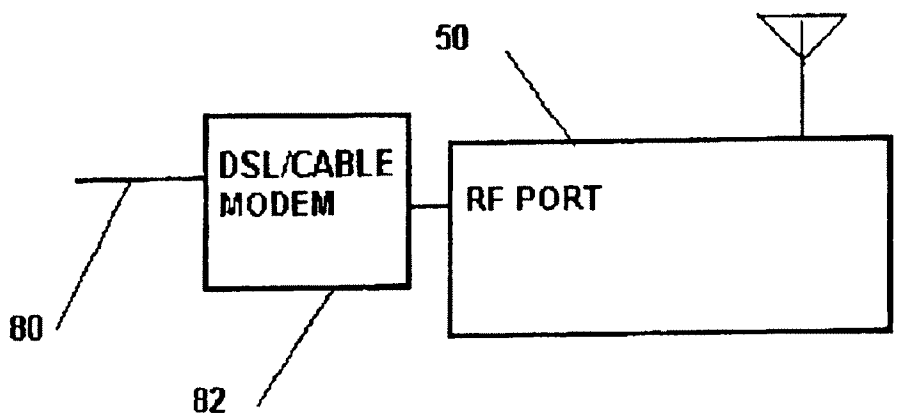
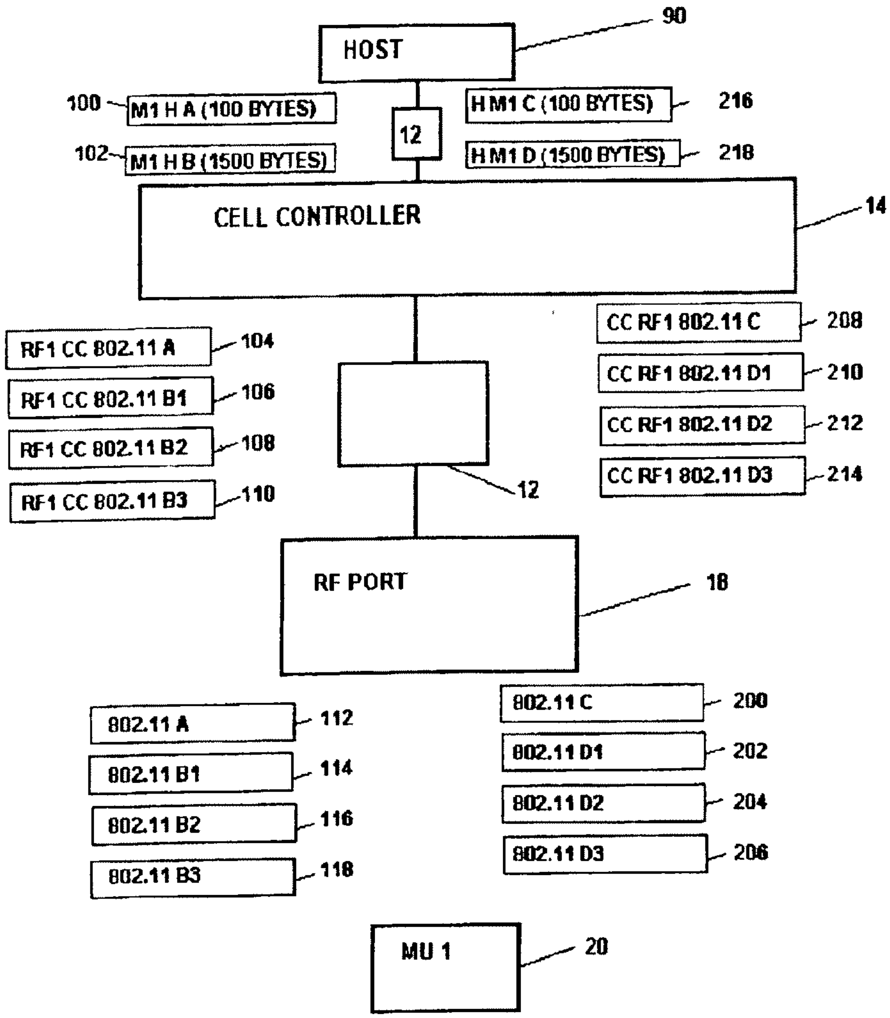


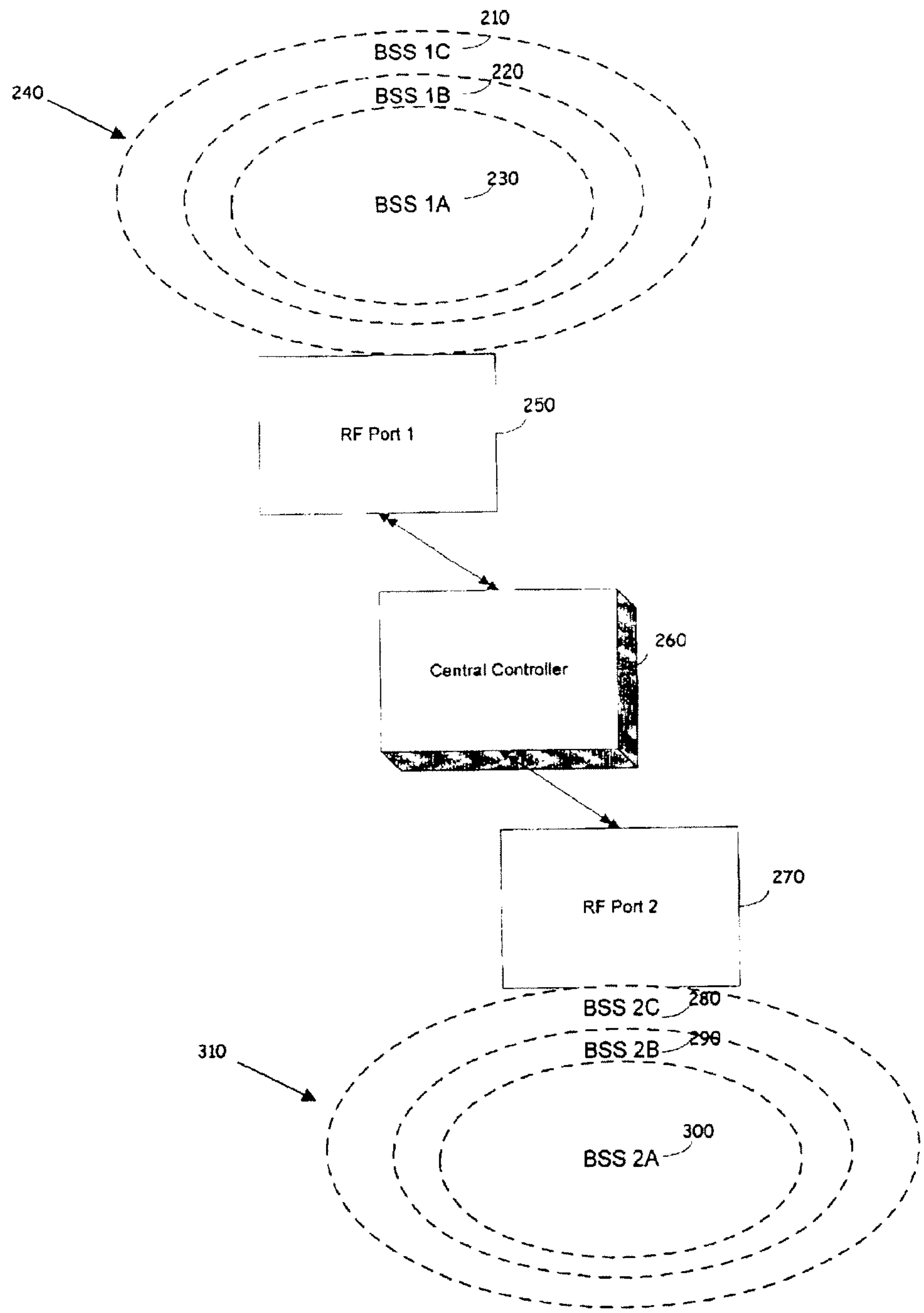
FIG.6



HOST
90
100
M1 H A (100 BYTES)
102
M1 H B (1500 BYTES)
12
H M1 C (100 BYTES)
216
H M1 D (1500 BYTES)
218
CELL CONTROLLER
14
RF1 CC 802.11 A
104
RF1 CC 802.11 B1
106
RF1 CC 802.11 B2
108
RF1 CC 802.11 B3
110
CC RF1 802.11 C
208
CC RF1 802.11 D1
210
CC RF1 802.11 D2
212
CC RF1 802.11 D3
214
12
RF PORT
18
802.11 A
112
802.11 B1
114
802.11 B2
116
802.11 B3
118
802.11 C
200
802.11 D1
202
802.11 D2
204
802.11 D3
206
MU 1
20

FIG. 7

FIG. 8



210
BSS 1C
220
BSS 1B
240
230
BSS 1A
RF Port 1
250
Central Controller
260
RF Port 2
270
BSS 2C
280
BSS 2B
290
310
300
BSS 2A

MULTIPLE WIRELESS LOCAL AREA NETWORKS OCCUPYING OVERLAPPING PHYSICAL SPACES

REFERENCE TO PRIOR APPLICATION

This application is a continuation-in-part of pending application Ser. No. 09/528,697, filed Mar. 17, 2000.

BACKGROUND OF INVENTION

This invention relates to wireless data communications networks, and in particular to arrangements for communications between mobile data handling units and a central computer using wireless data communications.

The assignee of the present invention supplies a wireless data communications system known as the Spectrum 24 System, which follows the radio data communications protocol of IEEE Standard 802.11. In the system as implemented, mobile units are in data communication with a central computer through access points. The access points may communicate with a central computer or computers over a wired network. Each of the mobile units associates itself with one of the access points. The access points in this system are functional to perform all the implemented requirements of the standard protocol, including, association and roaming functions, packet formulation and parsing, packet fragmentation and re-assembly encryption and system access control. In order to maintain order and reduce radio communications each access point must determine which of the data communications received over the wired network from the central computer is destined for a mobile unit associated with that particular access point. This requirement adds significant computational capacity to the access point, increasing the cost thereof.

In addition, in applications that must support a high volume of data communications from multiple users, such as systems supporting a self-service shopping system, hospital systems, systems that include paging or voice data links to many users, or systems supporting communicating with electronic shelf labels, additional access points are required to support the data communications traffic, increasing the overall system cost.

The cost of an operational access point is dependent not only on the complexity thereof and the requirement for high speed processing of data pockets for purposes of selecting those destined for mobile units associated with an access point, but the additional cost of the installation of electrical power to the location of the access point, and the cost of a power supply to convert AC electrical power to DC power for the circuits of the access point. Further cost may be involved in physically mounting the access point hardware and antenna.

In prior systems each access point is connected on an Ethernet wired network to the central computer. The access points are required to determine the identity of mobile units which have become associated with them and to extract from the data packets on the Ethernet network those packets addressed to a mobile unit associated with the access point. This requirement has led to significant processing burden for the access points and led to increased cost for the access points.

In the system described in my prior published International Patent Application WO 099 37047, published Jul. 22, 1999, the central computer communicates over an Ethernet wired network with an intelligent switching hub. Alternately a token ring network can be used. The switching hub

determines the destination of each packet and routes packets to an access point if the destination of the packet is a mobile unit associated with the access point. To achieve this function, the hub is an intelligent hub which maintains a routing list of mobile units and their associated access point according to the port of the hub.

In practice, the hub need only maintain a source list for those access points connected to the hub and mobile units associated with the access points connected to the hub. Thus, if a packet is received at a hub over the Ethernet with a destination address which is not associated with that hub, the packet is ignored. The hub will route the packet to an access point only if the destination address of the packet is identified on the list. When a packet is received on a hub port associated with a communications line connected to an access point, the source address is associated with the hub port in the list. The packet is routed either to the Ethernet connection or to another port according to the destination address.

By determining destination address in the hub and maintaining the association of a mobile unit address with an access point connected to a port of the hub in a routing list of the hub, the functionality required of the access points is greatly reduced. The access point acts merely as a conduit sending RF transmissions of packets received on its communication line, and receiving transmissions from associated mobile units and providing Ethernet packets to the hub. In addition, the access point must provide mobile unit association functions and other 802.11 protocol functions, as provided in the Spectrum 24 system, and may also provide proxy polling responses for associated mobile units that are in power saving mode.

The prior system may have a large number of access points, each with a memory containing program instructions for carrying out the various required functions. This distribution of processing makes it difficult to upgrade a system or to provide changes in system configuration because any upgrade or change may require changes to the program code in each of the access points. Such distribution of processing functions also makes system management functions, such as load balancing or access control more difficult.

It is therefore an object of the present invention to provide an improved wireless data communications methods and systems having lower cost, to enable the economical provision of reliable wireless data communications with increased capacity in complex installations or at reasonable cost or simple installations.

SUMMARY OF THE INVENTION

In accordance with the invention there is provided a system for providing wireless data communications between mobile units and a wired network. The system includes a plurality of RF ports having at least one data interface and arranged to receive formatted data signals at the data interface and transmit corresponding RF data signals and arranged to receive RF data signals and provide corresponding formatted data signal. There is also provided at least one cell controller, arranged to receive data signals from the wired network and to provide formatted data signals corresponding thereto and to receive formatted data signals and to provide data signals corresponding thereto to the wired network, the cell controller controls association of mobile units with one of the RF ports, provides formatted data signals for said mobile units to an associated RF port and receives formatted data signals from the mobile unit from the associated RF port.

In accordance with the invention there is provided an improvement in a wireless data communications network coupled to a data processing system, having a plurality of RF ports and mobile units, wherein the mobile units associate with one of the RF data communications ports to conduct data communications with said data processing system. The mobile units are assigned to one of the RF ports by a cell controller, and the cell controller is arranged to receive first data communications from the data processing system and to relay the data communications to an assigned RF port and to receive second data communications from the RF ports and relay the second data communications to the data processing system.

In accordance with the invention there is provided a method for operating a wireless local area network having at least one RF port, a plurality of mobile units and a cell controller coupled to the RF port. The RF is operated port to relay signals received from mobile units to the cell controller and to relay signals received from the cell controller to the mobile units. The cell controller is operated to control association of the mobile units with the RF port, including sending and receiving association signals between the RF port and the cell controller, and to send messages to and from the mobile unit via the RF ports.

In accordance with the invention there is provided an improvement in a mobile unit for use in a wireless data communications system, wherein the unit has a data processor and programs for the data processor and a wireless network adapter having a programmed processor and a radio module. The programmed processor performs first communications processor functions including control of the radio module and the data processor operates under the programs to perform second communications processor functions, including association with a radio access location of the wireless data communications system.

According to the invention there is provided an improvement in a wireless data communications system for providing data communications following a standardized protocol, wherein the protocol includes association of mobile units with radio access locations. At least one RF port is provided at a radio access location, which RF port comprises a radio module and an RF port processor in data communications with a programmed computer. The RF port processor performs first functions of the standardized protocol and the programmed computer performs second functions of the standardized protocol, including the association of mobile units with said radio access location.

According to the invention there is provided an RF port for use in a wireless data communications system comprising a radio module having a data interface and a transmitter/receiver for wireless data communications; and a digital signal processor having first and second data communications ports, random access memory and read-only memory. The second data communications port is coupled to the data interface of said radio module. The read-only memory is provided with a bootloader program for controlling the digital signal processor to load program instructions to the random access memory via the first communications port. According to the invention there is provided a method for operating an RF port having a radio module, a digital processor, random access memory and read-only memory. A bootloader program is stored in the read-only memory. The digital processor is operated to download instructions from a computer to the random access memory using the bootloader program and the RF port is operated under the downloaded instructions to send and receive messages using the radio module.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having a wired network interface, a data processor and an RF module. Signals are provided to the wired network interface having wireless address data and message data within a data packet addressed to the RF port using a protocol for the wired network. The processor is operated to provide wireless data signals having the wireless signal format for the address data and the message data to said RF module and operating the RF module is operated to transmit the wireless data signals as an RF signal modulated with the wireless signal format.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having an Ethernet interface, a data processor and an RF module. An Ethernet data packet is provided to the Ethernet interface, the Ethernet data packet encapsulating as data a data message having the wireless signal format. The data processor is operated to provide the data message to the RF module. The RF module is operated to transmit the data message as an RF signal.

According to the invention there is provided a method for receiving signals having a wireless signal format including wireless address data and message data at an RF port having a wired network interface, a data processor and an RF module. The RF module is operated to receive RF signals having the wireless signal format. The data processor is operated to receive wireless data signals from the RF module and provide data signals to the wired network interface comprising a data packet having a source address corresponding to the RF port using a protocol for the wired network, the data packet including the wireless address data and the message data.

According to the invention there is provided a method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port having an Ethernet interface, a data processor and an RF module. The RF message signals are received in the RF module and provided as data signals to the data processor. The data processor is operated to interpret address data in the data signals and, in dependence on the address data, said message data and said address data is encapsulated in an Ethernet packet, which is provided to the Ethernet interface.

In accordance with the invention there is provided a simplified wireless local area network system including a computer having a data processor and a memory, an RF port having an RF port data processor, an RF module and a data communications interface coupled to the computer. A first program is provided in the memory of the computer for operating the computer data processor to perform first wireless data communications functions, including association with mobile units. A second program is provided for operating the RF port data processor to perform second wireless data communications functions.

According to the invention there is provided a wireless access device for providing wireless access to a communication system. The device includes a modem for sending and receiving data messages on the communications system and an RF port, having a data interface coupled to the modem, a data processor and an RF module. The data is programmed to receive data messages from the modem, to format the messages for wireless data communications and to provide the formatted messages to the RF module for transmission by RF data signals to at least one remote station, and to receive RF data signals from the at least one remote station,

and to provide data messages to the modem to be sent on the communications system.

According to the invention there is provided a method for providing wireless access to the Internet. A modem having a data communications interface connected to an RF port is connected to the Internet. The RF port is configured for wireless data communication to at least one mobile unit having a predetermined wireless communications address. A mobile unit configured with the predetermined wireless communications address is provided for conducting RF data communications with the RF port. The RF port is arranged to relay communications between the mobile unit and the modem.

The apparatus and methods of the present invention provide RF ports as radio access locations which are less expensive than known access points and provide greater system management and flexibility. Much of the software used for controlling communications to and from mobile units is performed in a controller wherein software upgrades and changes are easily implemented. According to some embodiments, wherein instructions are downloaded to RF ports, it becomes easy to upgrade RF port instructions. System control is centralized, making management easier and enabling changes to access control and encryption functions. Priority for traffic purposes can also be established to facilitate digital telephony by giving priority to voice traffic. Accordingly, a system is provided that has significant flexibility using common RF port hardware to provide a wireless LAN having from one to hundreds of radio access locations.

According to the invention, the same RF port may provide multiple ESS identifications such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security.

For a better understanding of the present invention, together with other and further embodiments thereof, reference is made to the following description, taken in conjunction with the accompanying drawings, and its scope will be pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a wireless communications system in accordance with the present invention.

FIG. **2** is a block diagram illustrating one example of a mobile unit arranged to be used in the system of FIG. **1**.

FIG. **3** is a block diagram illustrating one example of an RF port for the system of FIG. **1**.

FIG. **4** is a more detailed block diagram of a preferred embodiment of an RF port in accordance with the invention.

FIG. **5** is a block diagram of an arrangement of a computer and RF port for providing a simplified wireless local area network according to the present invention.

FIG. **6** is a block diagram of an arrangement for providing wireless access to the Internet using the RF port of the present invention.

FIG. **7** is a diagram showing signal format according to one embodiment of the invention.

FIG. **8** is a diagram showing an compilation of RF ports having multiple ESS arrangements for providing overlapping, multiple wireless networks.

DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, there is shown an example of a wireless data communications system **10** according to the present invention for providing data communications between a central computer or a collection of computers on a wired network **16** and a plurality of mobile units **20**. While prior systems used access points at each radio access location, where the access points are capable of managing wireless communications with mobile units, the system of FIG. **1** uses simplified RF ports **18** at each radio access location to provide radio packet communications with the mobile units **20** using a wireless communications protocol, such as IEEE Standard 802.11, whereby the radio modules in the mobile units **20** monitor polling signals from the RF ports **18**, which are originated by the cell controllers **14** and associate with an RF port **18** for purposes of data communications. The system arrangement of FIG. **1** is especially effective in a large wireless local area network (LAN) system wherein it may be necessary to provide a large number of radio access locations. Typically such systems, operating at low power microwave frequencies, require radio access locations at about every 100 feet. Where the wireless LAN system must operate with mobile units, for example, portable computers or similar devices, located throughout a large facility, such as a business, hospital complex or university campus, many such radio access locations may be required, possibly several hundred. Accordingly there is an incentive to reduce the cost of the installation at each radio access location. According to the present invention the system configuration and operation are redesigned to reduce the cost of each individual radio access point. In addition, the system of the present invention provides a concentration of operational control in one or more central controllers **14**, making management of the system easier and making modifications and upgrades easier to install.

According to the invention, much of the functionality of the 802.11 protocol associated with the conventional access point, is removed from the device located at the radio access location and provided in a cell controller **14**, which may be located in conjunction with a switching hub **12**, connected to the wired network **16**, with which the wireless network **10** is associated. In particular the usual "access point" device is replaced with a simpler device **18**, herein referred to as an "RF port" which contains the RF module, which may be the same RF module used in the prior art access point, and simplified digital circuits to perform only a limited portion of the 802.11 media access control (MAC) functions performed by the prior art access point. In particular the RF port **18** preferably performs only functions of the access point that require a lower level of processing resources in terms of processor capacity and software complexity (memory requirement), and which are time critical. Other functions that are more processor intensive and require more complex programming, and which are not time critical, are relegated to one or more "cell controllers" **14**, which may perform these more complex functions for a plurality of RF ports **18**.

In order to perform the higher level processing functions of the access point in the cell controller **14**, according to the present invention, all messages directed to or from mobile units **20** associated with a particular RF port **18** are processed in a cell controller **14**. A system may have one or more cell controllers, which may comprise, e.g. Pentium-type board level computers, each of which is arranged and programmed to handle data message traffic and mobile unit associations for a selected plurality of RF ports **18**. A switching hub **12** may be interposed to provide message switching among the wired network connected to communications line **16**, RF ports **18** and cell controllers **14**. Each of the one or more cell controllers **14** acts as a virtual "access

point" for traffic addressed to its associated RF ports **18** and to the mobile units **20** associated with those RF ports. When a message is addressed to a mobile unit **20** is received on line **16**, switching hub **12** directs the message to the appropriate cell controller **14**, which reformats the message and relays the message to the appropriate RF port **18**, again through switching hub **12**. When the message is received by an RF port **18**, it is converted to a radio message and sent to the mobile unit **20** with a minimum of processing.

Likewise, when a message is received from a mobile unit **20** by an RF port **18**, it is converted to a digital message packet and relayed to the cell controller **14** associated with the RF port **18** through the switching hub **12**. The cell controller **14** parses the message for further relay in the system.

An important feature of a preferred embodiment of the invention is the fact that mobile unit association with the RF ports **18** is a function handled by the cell controller **14**. Accordingly, when a mobile unit **20** first becomes active, it sends an association request signal in response to a beacon signal sent by an RF port **18** (in response to direction by the cell controller). The association request signal is relayed by the RF port **18** to the cell controller **14**, which performs the processing required for association, including consideration of RF port loading. Cell controller **14** generates appropriate response signals to be sent by the RF port **18** to the mobile unit **20**. The cell controller **14** is in an appropriate position to evaluate the loading of the RF ports **18** under its control, and may therefore easily perform load leveling functions, for example, by providing a message to RF port **18** accepting or declining an association request. In addition, the cell controller **14** may receive load messages from other cell controllers **14** in the system **10** and thereby coordinate overall load management. As a mobile unit **20** moves from a location serviced by one RF port **18** to a location serviced by a different RF port **18**, the cell controller **14** receives information from the mobile unit **20** indicative of its reception of beacon signals from the various RF ports in the system and performs the necessary functions to support roaming of mobile unit **20**.

While in the system **10** of FIG. **1** the cell controllers **14** are shown as separate computers connected to switching hub **12**, the term "cell controller" is intended to refer to the logical functions performed by these computers rather than the computers themselves. As will become apparent, the cell controller may be implemented in a variety of ways other than as shown in the exemplary system **10** of FIG. **1**.

Implementation of a simplified RF port is achieved by performing "higher level" functions of the 802.11 protocol Media Access Control (MAC) in the cell controller and performing "lower level" functions in a simplified RF port.

The lower level functions are those that are hardware intensive and often time critical. The higher level functions are those that are software intensive and not time critical. One possible division of the exemplary 802.11 MAC functions is as follows:

Lower Level Functions (preferably to be performed at RF port)

Cyclic Redundancy Check (CRC)

Network Activity Vector (NAV)

Ready to Send/Clear to Send (RTS/CTS)

Header generation/parsing

Collision Avoidance

Frequency Hopping

Ack parsing/generating

Retransmission timeout

Higher Level Functions (preferably to be performed at Cell Controller)

Association processing

Roaming

Retransmission

Rate Control

Host Interface

The following optional (higher or lower) level MAC functions can be placed in either the higher or lower level categories.

Wired Equivalent Privacy encryption/decryption (WEP)

Fragmentation/Reassembly

Data Movement

Power Save Polling Support (PSP)

According to a preferred arrangement of the system of the invention, the lower level MAC functions are provided at the RF port, the higher level MAC functions are provided in the cell controller and the optional level functions can be provided at either the cell controller or the RF port.

A major advantage of the invention is a cost savings in hardware, processor capacity and storage capacity for the RF port. Since a system with, for example, one hundred or more radio access locations may be implemented with one or two cell controllers, the processor hardware and memory required for the higher level MAC functions need be provided only at the cell controllers. In fact, the capabilities of the overall system, for WEP encryption and other special functions, can be increased at modest cost by using a high performance board level personal computer or even a host computer as a cell controller.

By eliminating the higher level MAC functions from the radio access locations, the cost of the devices installed at those locations can be significantly reduced because of lower processor capacity and storage.

In connection with association and roaming functions the RF ports **18** provide beacon signals in response to commands generated by the cell controller **14**. When an association sequence is initiated by a mobile unit, the RF port **18** relays the association messages between the mobile unit **20** and the cell controller **14** during the association process, which is handled by the cell controller **14**.

In connection with message traffic to a mobile unit **20** from a network processor, message packets are routed by switching hub **12** to the cell controller **14** responsible for the mobile unit **20** addressed. The message is buffered and formatted by the cell controller **14** and in a preferred arrangement encapsulated by the cell controller **14** as a mobile unit packet within a wired network packet addressed to the responsible RF port **18**. This packet is routed to the RF port **18**. The RF port **18** extracts the mobile unit packet from the message and sends the packet to mobile unit **20** as a radio signal. The RF port **14** may also provide a CRC calculation and generate CRC data to be added to the message. The mobile unit **20** responds with an acknowledgment signal to the RF port **18**, which generates and sends an acknowledgment status message to cell controller **14**.

In connection with messages for systems connected to the wired network **16**, the mobile unit **20** sends a packet to the RF port **18** by radio signal. The RF port **18** filters received radio message packets according to the BSS (Basic Service Set) identifier in the packet and, if the packet has a BSS identifier associated with the RF port **18**, performs the CRC check as the packet is received. The RF port **14** then

generates and sends an acknowledgment signal to the mobile unit **20** and sends the received packet to cell controller **14**. Cell controller **14** buffers, parses and, if necessary, decrypts the packet and routes the packet to the host on network **16** through hub **12**.

The arrangement of RF port **18** may be identical to current access points used in the Spectrum 24 system with some of the access point software non-functional. Preferably the RF ports are simplified to reduce cost and power consumption. To reduce installation expenses the RF ports are powered via an Ethernet cable, which also connects RF ports **18** to switching hub **12** or to cell controller **14**. The RF ports can be arranged in a small package (e.g. portable radio size) with integrated diversity antennas and arranged for easy mounting, such as by adhesive tape or Velcro. Connection to the switching hub **12** is by Ethernet cable which is also provided with D.C. power, such as by use of a choke circuit, such as Pulse Model PO421 as described in my referenced International Application. The choke circuit may be built into an Ethernet connector and is available in this configuration.

The RF port **18** does not have to perform Ethernet address filtering and does not have to perform 802.11 association and roaming functions and can therefore have a lower level of processor capacity, software support, memory and power consumption. In one embodiment shown in FIG. **3** the RF port **18** includes only a digital signal processor (DSP) **38** which includes internal RAM and ROM. The DSP **38**, which may be one of the Texas Instruments TMS 320 family of DSP processor, such as the 5000 series, specifically the TMS 320 UC 5402 or the TMS 320 VC 5402. This DSP provides an interface between the Ethernet cable **46** and the RF module **42** in RF port **18**, as shown in FIG. **3**. The RF module **42** is provided in housing **36** with DSP **38**, DC/DC power supply **40** and carrying one or more antennas **44**. RF module **42** includes a 3860 or 3861 baseband processor, such as HFA 3860B, to interface with the digital portion of the RF port **18**, specifically DPS **38**. In one arrangement the ROM memory of the DSP **38** can be provided with "bootloader" firmware that downloads the necessary DSP software instructions from the cell controller **14** upon startup of the RF port **18**, and loads the instruction into the RAM of the DSP **38**.

The processors that are currently preferred as a possible lower level MAC engine are the TMS320UC5402 and the TMS320VC5402. These parts are functionally identical except for differences in power consumption (the VC5402 is currently in production and while the UC5402 is still being sampled). The basic configuration of the UC5402/VC5402 is:

- 100 MIPS execution rate
- 8 KB on chip ROM (organized as 4K×16 bits)
- 32 KB on chip RAM (organized as 16K×16 bits)
- Two 16 bit timers with 1 μs or better resolution
- Two High speed, full duplex serial ports (up to 50 Mbits/sec each) with smart DMA channel support
- One High speed 8 bit wide host/parallel port (160 Mbit/sec)
- Six DMA channels for general purpose use
- 16 bit external memory/IO Bus with internal wait state generation
- 16 interrupts with 3 instruction (30 ns) worst case latency
- 0.54 mW/MHz power consumption (30 mA@1.8 v at 100 MHz)
- Low Power Modes (6 mA, 2 mA, 2 μA depending on setting)
- Internal PLL that generates the system clock with an external crystal

This section will describe the use of a 5402 DSP **38** as a MAC engine for 11 Mbit/sec 802.11 DS systems. It could clearly be used in FH systems as well. We will focus on the how the 5402 interfaces to the Intersil 3860/1 baseband processor in RF module **42** and how it implements the lower level MAC functions.

The first issue is how the 5402 DSP **38** interfaces to the 3861 (much of what is said applies to the 3860 as well) and the rest of the RF module **42**. As shown in FIG. **4**, the 3861 processor **53** in RF module **52** of RF port **50** has 2 major interfaces, both serial. The first interface, labeled DATA, is used to transfer data between the MAC engine comprising DSP **64** and the 3861. It has four lines: T×D, T×C, R×D, and R×C and operates at up to 11 Mbits/sec. The exact rate depends on the transfer rate of the packet. The clock signals of both interfaces are generated by the 3861 and so transfers are controlled by the 3861. Both can be halted at any time by the 3861 as well as change rate. The second serial interface, labeled CONTROL is used to load commands into the 3861 and read status information from the 3861. This interface is a 4 wire bi-directional interface using one data line, one clock line, one "direction control" line, and a chip select line. This serial interface also can operate at up to 11 Mbits/sec. In addition to the serial interfaces, there are additional control and status lines such as Reset, TX_PE, RX_PE, TX_RDY, etc.

The 5402 DSP **38** has two sets of full duplex serial interfaces that are capable of operation up to 50 Mbits/sec (given a 100 MHz clock). They can be clocked using internal or external sources. In this design one of the sets of serial interfaces, labeled SER**1**, is used to connect to the high speed data lines of the 3861 interface **53**. The 5402 DSP **38** interfaces have the same basic lines (R×D, R×C, T×D, T×C) as does the 3861 and so they connect with minimal trouble. Although the 5402 uses 1.8 v for its core, its I/O lines are 3.3 v tolerant and so can interface to the 3861 without converters. In addition, they are fully static and so can deal the start/stop operation of the clock lines from the 3861.

Data transfer will be done under DMA control within the 5402 using what TI calls "Auto Buffering Mode." This provides essentially dedicated DMA channels for each serial port interface (two DMA channels per serial port interface). These channels access an independently operating bank of SRAM and so transfers have no impact on CPU performance. The CPU can start transfers in either direction and be notified via interrupt on their completion.

Interfacing to the control serial port on the 3861 interface **53** can be done in three different ways. The first, illustrated in FIG. **4**, utilizes the second serial port, labeled SER **2** on the 5402 DSP **64** with a small amount of combinatorial logic/buffering to convert between the single data line of the 3861 and the dual data lines of the 5402. Another approach is to use an external shift register that would perform serial/parallel conversion. This register would sit on the I/O bus of the 5402 and would be loaded/read by the 5402 and data shifted between it and the 3861. The third approach is to use an external buffer/latch on the 5402 I/O bus and "bit bang" the clock/data lines to the 3861. The second or third approaches free up the second serial channel for more other use such as providing high speed serial interfaces such as Ethernet or USB and in some applications would be preferred over the first. All require a small amount of external combinatorial logic and so the cost of all solutions is about the same.

The same logic would apply to interfacing to the synthesizer. It is accessed even less often than the control port of the 3861 and so a "bit banging" approach would work fine.

Finally, interfacing to the various control and status lines presented by the 3861 can be done via simple bi-directional

register/latch connected to the I/O bus of the 5402. The 5402 can read/write this register as it needs to control and monitor the 3861. It would be possible to combine all control/monitor functions (including the serial control interface) into a single 16 bit buffered register latch. Parallel control/status lines would be connected to particular lines of this latch. Serial control interfaces would also be connected and "bit banged" as necessary to move data between the 5402 and 3861.

The arrangement shown in FIG. **4** uses a Crystal CS 8900 A Ethernet controller **63** coupled to the parallel port of DSP **64** to interface to the Ethernet port **58**. An Ethernet connector/choke **58** receives cable **60** and provides DC power from cable **60** to DC/DC power supply **62**. The FIG. **4** RF port **50** includes spaced diversity antennas **54**, **56** to improve reception in multipath conditions.

A premise of this design is that the TI DSP is capable of implementing all lower level MAC functions without external hardware assistance. This, of course, is the most demanding model but we will find that the 5402 is up to the task. The most computational demanding tasks are the CRC-32 and WEP processing. The CRC-32 calculation is performed over the entire packet and must be completed in time to generate an ACK should the CRC turn out to be correct (or to attach the calculation result to an outgoing packet on transmission). This means that the CRC calculation must be performed in near real-time during packet transfer between the 3861 and 5402. TI has shown in an application note that a CRC-32 calculation can be made by a 5000 series DSP in 13 instructions. At 100 MIPS this is about 130 ns. At 11 Mbit/sec, a byte takes about 770 ns to transfer and so we have plenty of time to do the CRC. When receiving a packet, the serial port would be transferring the data from the 3861 to SRAM within the 5402. At the same time the CPU within the 5402 would be reading each received byte from SRAM and calculating the CRC. It would of course have to make sure that it did not overrun the receive buffer, but that would be a relatively simple task. Much the same process would happen during transmission. In either case, the CPU has lots of time to do the CRC.

The WEP processing if performed in the RF port **50**, is a harder function to perform than CRC-32 since it includes both an RC4 encryption function and a second CRC-32. At the same time it does not need to be completed prior to ACK generation/reception nor is performed on every packet (just data packets). The RC4 encryption function consists of two parts: building the encryption table (a 256 byte table) using the selected key and doing the encryption/decryption process. Based on sample code, it is estimated that building the table would require about 1200 instructions (12 ms at 100 MIPS) and the encryption/decryption process would require about 12 instructions/byte. There is no difference in this cost for 40 or 128 bit keys. The WEP CRC-32 would require another 13 instructions per byte.

The per byte computational burden for WEP would thus be about 25 instructions or about 250 ns at 100 MIPS. When added to the packet CRC-32, the total load would be around 38 instructions/byte. As we pointed out, at 11 Mbit/sec we have about 77 instructions/byte available, so we are spending about 50% of the CPU on CRC/WEP tasks. The biggest issue is the 1200 clocks (12 us) required to build the encryption table during receive (For transmission, the calculation can be done prior to starting packet transfer). Pausing to create the table would put the CPU about 18 bytes (12 us at 770 ns/byte) behind in the CRC/WEP/CRC calculation process. It would require about 40 data bytes to catch up (1200 clocks/30 extra clocks per byte) in both

packet CRC and WEP/CRC functions. Since the minimum TCP/IP header is at least 40 bytes (plus any user data), we should have enough time. In any case if we are a little late in WEP/CRC calculation, no harm is done. An alternative approach would be to catch up first for the packet CRC calculation and then catch up with WEP/CRC.

After CRC and WEP/CRC processing, the next most critical activity is header parsing on receive and generation on transmit. This is because of the need to identify packets for the station and generate appropriate responses. On receive, the processor must parse two or three 48 bit addresses and at least a 16 bit header command field. After the packet completes, an ACK may need to be generated.

The 5402 can easily handle these functions. Since these functions are performed prior to WEP processing, the CPU has 64 instructions/byte (77–13) to perform these functions. Since many of them can be performed on a 16 bit or even 32 bit basis (the 5402 supports both 16 and 32 operations), there may be up to 128 or 256 instructions per data item (i.e. 256 instructions to perform a 32 bit address check). These functions are performed at 2 Mbit using a 1 MIPS 188 CPU. We have a 100 MIPS CPU to do the same tasks at 11 Mbit/sec.

ACK generation is likewise relatively simple. An ACK frame is only 14 bytes long, including the 4 CRC-32. Given there is a long (80 us) preamble, we have 8000 instructions to prepare the ACK. The same applies to RTS/CTS exchanges.

There are two 16 bit timers available on the 5402. In this model, one would be used for TSF timing and the other for all other functions. There are really only a few other timer functions: NAV, Retransmission, collision avoidance slot countdown, etc. Retransmission and collision avoidance activities go on only when waiting for an ACK or to start a retransmission after detection of an idle network. In such cases there is no data transfer going on and so there is lots of CPU cycles available.

Support for MU PSP function can be done in a variety of ways, depending on how much, if any, external hardware is provided. The 5402 provides a variety of means of conserving power. The first is simply to slow down the CPU clock via the software controlled PLL within the unit. The 5402 generates internal clocks via a PLL that is driven by either an external crystal or clock. The PLL multiplies the base frequency of the crystal/external clock by a factor determined by software. Hence one means of controlling power consumption is simply to slow down the CPU clock. Since the CPU portion of the processor consumes most of the power, slowing it down has the biggest affect on power consumption.

The second approach is use one of the IDLE modes of the processor. IDLE1 stops the CPU clock entirely but leaves everything else running. Power consumption in this mode is on the order of 6 mA at 100 MHz. The CPU can be restarted by any interrupt (internal or external). In IDLE2 the system clock is stopped and this reduces consumption to 2 mA. In IDLE3, all system functions are stopped and consumption is reduced to around 2 ua. In all cases all state is retained. In IDLE2 and IDLE3, an external interrupt is required to restart the CPU. In such cases an external, low power timer would be required.

Thus with no external hardware, power consumption could be reduced to at least 6 mA and perhaps less. With a simple external timer, one could get down to microamps.

The bottom line is that the vast CPU power of the 5402 allows all lower level MAC functions to be performed in software. Furthermore it has sufficient power and memory to

handle additional "higher level" functions such as packet retransmission, fragmentation, and reassembly that can also be done in a cell controller.

The system **10** of the present invention is compatible with IEEE Standard 820.11 and accordingly will operate with any mobile units **20**, including existing units, which are compatible with the same standard. However, the improvements applied to the RF ports **18**, reducing the complexity and cost of these units can also be applied to the mobile units **20**, which have sufficient main processor capacity to handle the mobile unit functions corresponding to the higher order MAC functions.

Referring to FIG. **2** there is shown a block diagram for a mobile unit **20** having a mobile unit computer **22** and a WLAN adapter **24** connected thereto to provide wireless communications to the system **10** of FIG. **1**. In the mobile unit **20** of FIG. **2**, the lower level MAC functions are performed in WLAN adapter **24**, which also includes RF module **28** and antenna **29**. The configuration of WLAN adapter **24** may be similar to existing adaptors, but preferably adapter **24** is simplified to perform only the lower level MAC functions of the IEEE 802.11 protocol and allow special software **34** in host computer **22** to perform the higher level MAC functions, such as association and roaming. In a preferred arrangement the MAC functions of adapter **24** are performed in a digital signal processor **26**, as described below, which may be the same type DSP described with respect to RF port **50**.

This section addresses how the 5402 DSP could be used as a MAC engine in Mobile Unit configurations. There are two considerations in building MU WLAN solutions. The first is the location of those MAC functions, while the second is the physical interface to the host.

The location of the upper level MAC functions may vary considerably. Some possibilities are:

All functions on MAC engine DSP processor **26**

All functions on host processor **22**

Roaming/association on host processor **22**, rest on MAC engine **26**

Roaming/association/retransmission on host **22**, rest on MAC engine **26**. The choice of the location of the higher level MAC functions has a major impact on the cost of MU WLAN adapter. If one is willing to place at least some of the higher level functions on a host processor **22**, then one could get by with just the 5402 on the WLAN adapter. Possible functions to place on the host would be roaming and association control. Higher level functions such as retransmission and fragmentation/reassembly could be left on the 5402. This split would permit significant savings, since another processor/memory subsystem would not be needed on the WLAN adapter. There are two reasons for not placing all of the MAC functions on the 5402. The first is memory space on the 5402 is only 32 KB of SRAM for both code and data. In some MAC implementations such as frequency hop, the code space alone exceeds 32 KB. The second reason is that the software on the 5402 is oriented toward meeting hard, real-time tasks such as CRC and WEP processing. Trying to add software intensive tasks would only complicate the process.

If another processor was required, such as an ARM or perhaps a second 5000 Series processor, the upper level functions could be added to it.

Alternatively one could place all the MAC functions on a faster and/or bigger version of the 5402 processor. Such a processor would likely have a higher clock rate (current members of the 5000 Series can be clocked as high as 160 MIPS) and more memory (say 64 KB instead of 32 KB).

Both the second processor as well as a faster/bigger 5402 would consume additional power as well as adding cost.

This section will describe one approach of how a MU WLAN adapter can be arranged for various hardware host interfaces using the 5402. It assumes that enough of the upper level MAC functions have been offloaded to a host processor so that only the 5402 is required on the PLAN adapter. A second processor could be added to any of the solutions outlined below.

In all of the following solutions, it is assumed that the runtime code for the 5402 is loaded from an external source (such as computer **22**) via the host interface **32**. This eliminates the need for flash memory on the adapter card, saving several dollars in the process. It should be pointed out that the 5402 comes with 8 KB of mask programmable ROM and a bootloader program (required for the USB and Ethernet host interfaces) would be placed in it. The bootloader would be smart enough to download the runtime code instructions over whatever serial interface was available.

The simplest interface of all would be for a host to use the Host Port on the 5402. This port operates as a dual port interface into the memory within the 5402. It would not be a standard interface but would be quite suitable for dedicated systems. Using it, computer **22** can read/write memory on a random or sequential basis. It is an 8 bit interface and can operate as fast as 160 Mbit/sec. When operated in random access mode, the computer **22** generates a 16 bit address using two writes to the port and then performs either a read or write operation. Such a mode allows a host to set up command blocks and the like within the memory of the 5402. Sequential mode allows a host to transfer data in and out of the 5402 memory very quickly (160 Mbit/sec). This would be used for transferring data.

If this approach was used, the only digital component on the WLAN adapter would be the 5402.

In the system of FIG. **1**, the cell controller **14** is a board level personal computer coupled to the switching hub **12** preferably by 10 M bit and 100 Mb Ethernet ports. For smaller systems a 350 MHz Pentium computer with 16 MB RAM may be used. For larger systems having many RF ports a 500 MHz Pentium with 64MB RAM is appropriate. Communications to and from the wired network are preferably carried out at 100 MHz. Communications to and from RF ports may be carried out at 10 MHz. A second cell controller may be supplied for larger systems and/or to provide backup in the event one cell controller fails. Reliability can be enhanced by providing dual fans and dual power supplies. A flash disk memory may be used for reliability. Alternately, the cell controller **14** may be built into the switching hub **12** or into a host processor.

The operating system for the cell controller **14** may be a real time operating system, such as VRTX or QNX, which provides multitasking, a full network stack and utilities. Web based management utilities, which are client side java based, are provided for maintaining the configuration of the cell controller **14**, the RF ports **18** and status of the mobile units **20**.

The cell controller **14** includes applications to provide mobile unit association management, roaming and packet buffer management. These applications are similar to those performed by current access points in the Spectrum 24 system. The cell controller **14** may also provide QoS support, user authorization and configuration management. Placing these functions on a personal computer cell controller facilitates system management and program updates using available programming tools. Further, modifications to authorization or management functions need only be

installed into the cell controller **14**, and no modification to the software of the RF ports **18** is required.

The cell controllers **14** handle routing of all messages to or from the mobile unit. The cell controller buffers message packets received from the wired network and determines the appropriate RF port **18** with which the addressed mobile unit **20** is associated and sends the packet to the RF port **18**. The cell controller **14** can additionally perform WEP encryption/decryption and the CAC associated therewith.

The cell controller **14** may also the additional function of maintaining and downloading firmware to the RF ports **18**. Upon power up the RF ports **18** use a bootloader routine stored in ROM to send a download request to cell controller **14**. The cell controller then downloads firmware to the RF port **18**, including configuration information such as channel assignment, ESS and BSS identification. The cell controller **14** and RF ports **18** additionally share a common TSF clock.

The mobile unit computer **22** of mobile unit **20** is provided with similar software to perform the higher level MAC functions as outlined above. Advantageously, the software **34** can be programmed using the same operating system as provided for the computer, and thereby provide a user interface, such as Windows, which is familiar to the user. The mobile unit software **34** provides the MAC functions of header building, roaming and association. The mobile unit computer **22** may also download firmware to the processor in the WLAN adapter **24**.

As evident from the forgoing description, the hardware for RF port **18** and WLAN adapter **24** of mobile unit **20** can be substantially similar, with the possible exception of the interface to an Ethernet network or to a mobile unit host. Further, the logical cell controller function and the higher order MAC functions performed by the mobile unit host processor can be performed on any computer system.

Using the RF port **18** of the present invention coupled to a computer system, it is possible to provide either a mobile unit or a wireless network according to the software provided. Since the software for RF port **18** may be downloaded from a host system a simple combination of a computer and one or more RF ports can function as either a WLAN mobile unit as a WLAN host or both, by providing function selectable firmware to the processor in the RF port.

In the arrangement shown in FIG. **5**, a personal computer **70** is provided with software **72** and connected to one or more RF ports **50**A, **50**B to provide a complete host system for wireless data communications. This arrangement could be used, for example, in a small business wherein office equipment is connected to server **70** by a wired network for conventional LAN operation and one or more RF ports **50** are also connected to server **70** on the LAN system to provide data communications between the server **70** and mobile units. The server can perform the higher order MAC functions and download firmware instructions to the RF ports. Alternatively, the firmware instructions can be installed on PROM memory in the RF ports.

FIG. **6** shows an arrangement for providing wireless access to the Internet using the RF port **50** of the present invention. Internet access over communications line **80** to modem **82** may be provided by cable, DSL or fiber optical transmission. RF port **50** may be provided with MAC firmware on PROM or may be configured with a bootloader program to download firmware from an ISP server. When installed in a home or office, mobile units **20** can associate with RF port **50** to initiate Internet access. The ISP server may perform the higher level MAC function, or they may be provided in RF port **50**.

The mobile units **20** may be the personal computers **22** in a home or office with a WLAN adapter **24** as shown in FIG. **2**.

FIG. **7** illustrates an example of communications formats that might be used in the various system embodiments of the present invention. The FIG. **7** example assumes that the configuration includes a host **90** connected to a dedicated cell controller **14**, which is likewise connected to RF port **18**. It should be clearly understood that the logical cell controller functions may be performed in host **90**, particularly in a simple system.

In the FIG. **7** example host **90** sends message "A" having 100 data bytes via an Ethernet packet **100** to cell controller **14**. Packet **100** has a destination address of the Mobile unit (M1), a source address of the host (H) and includes data (A). Cell controller **14** formats the data in 802.11 format with the destination corresponding to mobile unit (MU1) **20**. The cell encapsulates this 802.11 packet with data A into an Ethernet packet **104** addressed to RF port **1** (RF1) from the cell controller (CC).

RF port **18** receives the Ethernet packet **104** from cell controller **14** and generates and sends an RF packet **112** in 802.11 format to mobile unit **20**, including data A. It should be understood that 802.11 header generation can be provided at either the cell controller **14** or the RF port **18**, but packet **104** must include mobile unit identification data either as an 802.11 header or otherwise to enable RF port **18** to generate the header. RF port **18** additionally performs the CRC computation and adds the result to the 802.11 packet **112**.

A second message "B" having 1500 bytes of data is also shown as originating as Ethernet packet **102** from host **90** to cell controller **14**. Cell controller fragments data message B into three fragments B1, B2 and B3 to accommodate the 500 byte data limit of 802.11 packets. These three fragments are sent as Ethernet packets **106**, **108**, **110** to RF port **18**, which transmits RF signal packets **114**, **116**, **118** to mobile unit **20**.

Reverse communication is similar. Message C has 100 bytes and is sent by mobile unit **20** to RF port **18** as 802.11 RF signal packet **200**. RF port **18** encapsulates this message into Ethernet packet **208** and sends it to cell controller **14**, which extracts the destination information and data to provide Ethernet message **216** to the host **90**. A larger message D is sent as message fragments **202**, **204**, **206** to RF ports **18**, relayed as Ethernet packets **210**, **212**, **214** to cell controller **14** and sent as a reassembled Ethernet packet **218** to host **90**.

Referring now to FIG. **8**, shown is an application of the central controller/RF port model that may be used to set multiple overlapping ESS LANs for use in the same or overlapping physical space. Shown in FIG. **8** is a central controller **260** which is associated with two RF ports, RF port **1 250** and RF port **2 270**. The central controller **260** may be associated with more than two RF ports, but two are shown for illustration purposes. Each RF port **250**, **270** provides coverage for a wireless LAN in the physical areas **240**, **310**.

FIG. **8** further illustrates the concept of providing multiple ESS identifications through the same RF port and cell controller such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security. Thus, RF port **1 250** may be configured so as to support separate BSS networks **1**A **230**, **1**B **220** and **1**C **210**, all of which occupy the same physical space **240**. The RF port may support more than three BSS networks, but three are shown for illustration purposes. Similarly, RF port **2 270** may be configured so as to support BSS networks **2**A **300**, **2**B **290** and **2**C **280** all of which occupy the same physical space **310**. Using the configuration as shown in FIG. **8**, multiple ESS LANs may be coordinated by the central controller **260** in the physical space **240** and **310**. ESS A consists of BSS **1**A **230** and BSS

2A **300**. ESS B consists of BSS 1B **220** and 2B **290**. ESS C consists of BSS 1C **210** and 2C **280**.

As discussed in further detail above the RF ports **250**, **270** preferably performs only functions of the access point that require a lower level of processing resources in terms of processor capacity and software complexity (memory requirement), and which are time critical. Other functions that are more processor intensive and require more complex programming, and which are not time critical, are relegated to one or more cell controllers **260**, which may perform these more complex functions for a plurality of RF ports **250**, **270**. In the case illustrated in FIG. **8**, the central controller handles the necessary processing of multiple ESS LANs A, B, C in the same physical space **240** and **310**.

One application of multiple ESS LANs may be found on a public place, such as an airport where, for example, three levels of wireless networks may operate. A first public network level with generally open access to a wireless local area network that might provide, for example, public wireless telephone or internet access. A second network level would involve airport operations, such as luggage handling, aircraft servicing, etc. A third network level may be reserved for emergencies and security. Devices using the network can be restricted by the cell controller as to which virtual network they can access using the same RF port of the wireless network system. The cell controller would thereby control communications between mobile units accessing an RF port and the three or more virtual networks such that, for example, a member of the public using a publicly available device could only access the public functions of the system and therefore only have access to the lowest level of virtual wireless network. Other personnel, such as airport employees, may have access to the public level and also have access to the airport operational network. The security-based network would be available for select airport personnel such as management and security officers.

The cell controller performs the function of determining which ESS network a mobile unit communicating with an RF port associated with the cell controller is operating on, and thereby controls the direction of communication from the cell controller to the network. The cell controller can verify the multiple levels of security provided in connection with the access by the mobile unit devices, and in addition can prioritize communications so that higher priority communications such as security communications are given greater access to the system during higher traffic conditions. For example, in the three-tier embodiment discussed above, the security network could have a feature to disallow all other network access in an emergency situation.

A similar multi-virtual LAN network may be also useful in a health care facility wherein different networks are used for security, medical care, personal and public information.

While there has been described what is believed to be claimed in the above-identified application those skilled in the art will recognize that other and further modifications may be made without departing from the scope of the invention and it is intended to claim all such changes and modifications as fall within the true scope of the invention.

I claim:

1. A method for operating multiple overlapping wireless local area subnetworks, the method comprising:

providing a common cell controller coupled to a plurality of RE ports, wherein the common cell controller in conjunction with each RF port provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports;

using the cell controller to provide multiple service set identifications through each RF port, wherein each service set identification is associated with a corresponding wireless subnetwork,

wherein said RF ports are operated to perform low level MAC functions and to relay signals received from mobile units to said cell controller and to relay signals received from said cell controller to said mobile units,

and wherein said cell controller is operated to control association of said mobile units with said RF port, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area subnetworks occupying common physical space.

2. A method for operating a wireless local area network as specified in claim **1**, wherein signals are sent, between said RF port and said cell controller using a first data protocol, and wherein signals are sent between said RF ports and said mobile units using a second data protocol, and wherein said signals between said RF port and said cell controllers comprise data packets using said first data protocol encapsulating data packets using said second data protocol.

3. A method for operating a wireless local area network as specified in claim **2** wherein said first protocol is an Ethernet protocol.

4. A method for operating a wireless local area network as specified in claim **3** wherein said second protocol is an IEEE Standard 802.11 protocol.

5. A method for operating a wireless local area network as specified in claim **4** wherein said at least two wireless local area subnetworks comprise a subnetwork for public use and a subnetwork for secure use.

6. A method for operating a wireless local area network as specified in claim **5**, wherein upon activation of said subnetwork for secure use, suspending service on said subnetwork for public use.

7. The method of claim **1** wherein the RF port includes a radio module, a digital processor, random access memory and read-only memory, the method further comprising:

storing a bootloader program in said read-only memory,

operating said digital processor to download instructions from a computer to said random access memory using said bootloader program, and

operating said RF port under said downloaded instructions to send and receive messages over at least two wireless local area subnetworks occupying common physical space using said radio module.

8. A method as specified in claim **7**, wherein said step of operating said RF port comprises receiving messages from said computer including protocol message portions for RF message transmission, and transmitting said message including said protocol message portions as an RF signal.

9. A method as specified in claim **8**, wherein said step of operating said RF port comprises receiving RF messages having an RF protocol and sending said RF messages to said computer as data signals encapsulated in a further message protocol.

10. A method as specified in claim **9** further comprising interpreting said RF protocol using said downloaded instructions and sending said RF messages to said computer only if said RF messages include an identification of said RF port.

11. A method as specified in claim 7 wherein said downloaded instructions configure said computer and said RF port to operate as an access point for communication with mobile units.

12. A method as specified in claim 7 wherein said computer is operated to control association of said mobile units with said computer and RF port.

13. A method as specified in claim 7 wherein said downloaded instructions configure said computer and said RF port to operate as a mobile unit for communications with access points.

14. A method as specified in claim 7 wherein said downloaded instructions configure said computer and said RF port to operate as either an access point or a mobile unit under control instructions form said computer.

15. A method for transmitting signals having a wireless signal format using an RF port, the RF port having an Ethernet interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions, and wherein the wired network comprises at least one of a physical entity and a logical entity to perform high level MAC functions, the method comprising:

providing an Ethernet data packet formatted according to high level MAC functions over the wired network to said Ethernet interface, said Ethernet data packet encapsulating as data a data message having said wireless signal format according to high level MAC functions on said wired network;

operating said data processor to provide said data message to said RF module;

operating said RF module to transmit said data message as an RF signal to a mobile unit; and

operating said RF module to transmit said data message as an RF signal over at least two wireless local area subnetworks occupying common physical space.

16. A method as specified in claim 15 further comprising operating said data processor to perform a cyclic redundancy computation on said data message and adding the result thereof to said data message.

17. A method as specified in claim 15 further comprising operating said data processor to control said radio module.

18. A method for receiving signals having a wireless signal format including wireless address data and message data at an RF port, the RF port having a wired network interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions and the wired network is configured to perform high level MAC functions, the method comprising:

operating said RF module to receive RF signals from at least two wireless local area subnetworks occupying common physical space having said wireless signal format;

operating said data processor to receive wireless data signals from said RF module and provide data signals to said wired network interface comprising a data packet having a source address corresponding to said RF port formatted according to high level MAC functions on said wired network, said data packet including said wireless address data and said message data.

19. A method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port, the RF port having an Ethernet interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions and the wired network is configured to perform high level MAC functions, the method comprising:

receiving said RF message signals in said RF module from at least two wireless local area subnetworks occupying common physical space;

providing said signals as data signals to said data processor;

operating said data processor to interpret address data in said data signals; and,

in dependence on said address data, encapsulating said message data and address data in an Ethernet packet and providing said Ethernet packet to said Ethernet interface for transmission on said wired network according to high level MAC functions.

20. A method as specified in claim 19 wherein said data processor is operated to encapsulate said address data in said Ethernet packet.

21. A method as specified in claim 19 wherein said data processor is further operated to perform a cyclic redundancy computation on said message data and to compare the result thereof with corresponding data received in said data signals.

22. A method as specified in claim 19, further comprising operating said data processor to control said radio module.

23. A simplified wireless local area network system comprising:

a computer having a data processor and a memory;

a plurality of RF ports, each RF port having an RF port data processor, an RF module and a data communications interface coupled to said computer,

a first program in said memory of said computer for operating said computer data processor to perform high level MAC functions for said plurality of RF parts, said functions including association with mobile units via at least two wireless local area subnetworks occupying common physical space; and

a second program for operating said RF port data processor to perform low level MAC functions.

24. A system as specified in claim 23 wherein said second program operates said RF port data processor to perform second wireless data communications functions, including control of said RF module.

25. A system as specified in claim 23 wherein said second program operates said RF port data processor to perform second wireless data communications functions, including cyclic redundancy check functions.

26. A system as specified in claim 23 wherein said second program is stored in said computer memory and wherein said RF port data processor is arranged to download said second program.

27. A wireless access device for providing wireless access to a communication system, comprising a modem for sending and receiving data messages between said communications system and an RF port, the RF port comprising a data interface coupled to said modem, a data processor and an RF module, said data processor being programmed to receive data messages from said modem, to format said messages for wireless data communications and to provide said formatted messages to said RF module for transmission by RF data signals to at least one mobile unit via at least two wireless local area subnetworks occupying common physical space, and to receive RF data signals from said at least one mobile unit via at least two wireless local area subnetworks occupying common physical space, and to provide data messages to said modem to be sent on said communi-

cations system, wherein said RF port performs low level MAC functions and said communication system performs high level MAC functions.

28. A wireless access device as specified in claim 27 wherein said communications system is a DSL communications system connected to the Internet, and wherein said modem comprises a DSL modem.

29. A wireless access device as specified in claim 27 wherein said communications system is a two-way cable communications system connected to the Internet, and wherein said modem comprises a cable modem.

30. A wireless access device as specified in claim 28 wherein said communication system comprises a fiber optic system, and wherein said modem comprises a fiber optical modem.

31. A method for providing wireless access to the Internet, comprising:

providing a modem coupled to the Internet and having a data communications interface connected to an RF port,

configuring said RF port for wireless data communication to a mobile unit having a predetermined wireless communications address, and

providing at least one mobile unit configured with said predetermined wireless communications address for conducting RF data communications with said RF port via at least two wireless local area subnetworks occupying common physical space, said RF port being arranged to relay communications between said mobile unit and said modem, wherein said RF port performs low level MAC functions and said Internet performs high level MAC functions.

32. The method specified in claim 31 wherein said step of providing said mobile unit, comprises providing a computer having an RF port.

33. A system for providing wireless data communications between mobile units and a wired network operating according to a wireless data communications protocol having high level MAC functions including association and roaming functions, comprising:

at least one RF port performing lower level MAC functions, said at least one RF port having an RF module for sending and receiving data messages to said at least one mobile unit using capable of operating via at least two wireless local area subnetworks occupying common physical space, having a wired interface for sending and receiving data messages to and from said wired network using a wired communications protocol, and a programmed processor for relaying data messages received on said wired interface using said RF communications protocol and for relaying data messages received by said RF module using said wired communications protocol; and

at least one cell controller for sending data messages to said wired interface of said RF port and for receiving data messages from said RF port wherein said cell controller performs said high level MAC functions.

34. A system as specified in claim 33, wherein there are provided a plurality of said RF ports, and wherein said cell controller is arranged to address said data messages to said RF ports using said wired communication protocol.

35. A system as specified in claim 33 wherein said at least one mobile unit is associated with one of said RF ports, and wherein said processor is programmed to interpret source address data received in said RF communications protocol and for relaying a received message using said wired communications protocol only if said source address data corresponds.

36. A system as specified in claim 33 wherein said cell controller is arranged to provide messages to said RF port comprising mobile unit address data and message data encapsulated in data packet following said wired communication protocol.

37. A system as specified in claim 36 wherein said cell controller is arranged to provide said mobile unit address data and said message data in said RF communications protocol encapsulated in said wired communication format.

38. A system as specified in claim 33 wherein said RF port is arranged to encapsulate messages received by said RF module in a data packet using said wired communication protocol.

39. The method of claim 1 wherein the cell controller provides extended service set identifiers (ESS).

40. The method of claim 1 wherein the cell controller provides basic service set identifiers (BSS).

41. The method of claim 1 wherein the RF port allocates data bandwidth amongst the service set identifications based on commands from cell controller.

42. The method of claim 1 wherein the RF port generates an 802.11 beacon for each service set identifier.

43. The method of claim 1 wherein the cell controller determines which one of the multiple overlapping wireless local area subnetworks a mobile unit communicating through an RF port is operating on.

44. The method of claim 1 wherein the cell controller verifies levels of security provided in connection with access by mobile units to the multiple overlapping wireless local area subnetworks.

45. The method of claim 1 wherein the cell controller prioritizes communications through the multiple overlapping wireless local area subnetworks.

* * * * *

EXHIBIT B

US007173923B2

(12) **United States Patent**
Beach

(10) **Patent No.: US 7,173,923 B2**
(45) **Date of Patent: *Feb. 6, 2007**

(54) **SECURITY IN MULTIPLE WIRELESS LOCAL AREA NETWORKS**

(75) Inventor: **Robert Beach**, Los Altos, CA (US)

(73) Assignee: **Symbol Technologies, Inc.**, Holtsville, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 883 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/037,225**

(22) Filed: **Oct. 25, 2001**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 09/780,741, filed on Feb. 9, 2001, which is a continuation-in-part of application No. 09/528,697, filed on Mar. 17, 2000.

(51) **Int. Cl.**

H04Q 7/24	(2006.01)
H04L 12/28	(2006.01)
H04L 12/56	(2006.01)

(52) **U.S. Cl.** **370/338**; 370/401

(58) **Field of Classification Search** 370/401, 370/338, 466, 419–420

See application file for complete search history.

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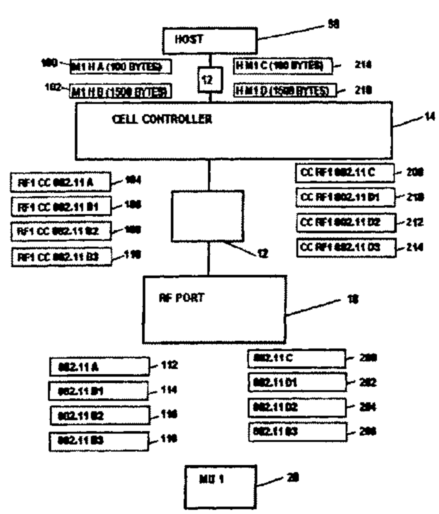
(57) **ABSTRACT**

A wireless local area network is provided with simplified RF ports which are configured to provide lower level media access control functions. Higher level media access control functions are provided in a cell controller, which may service one or more RF ports that are capable of operating based on a pre-assigned security level. Mobile units can also be configured with the higher level media access control functions being performed in a host processor.

16 Claims, 7 Drawing Sheets



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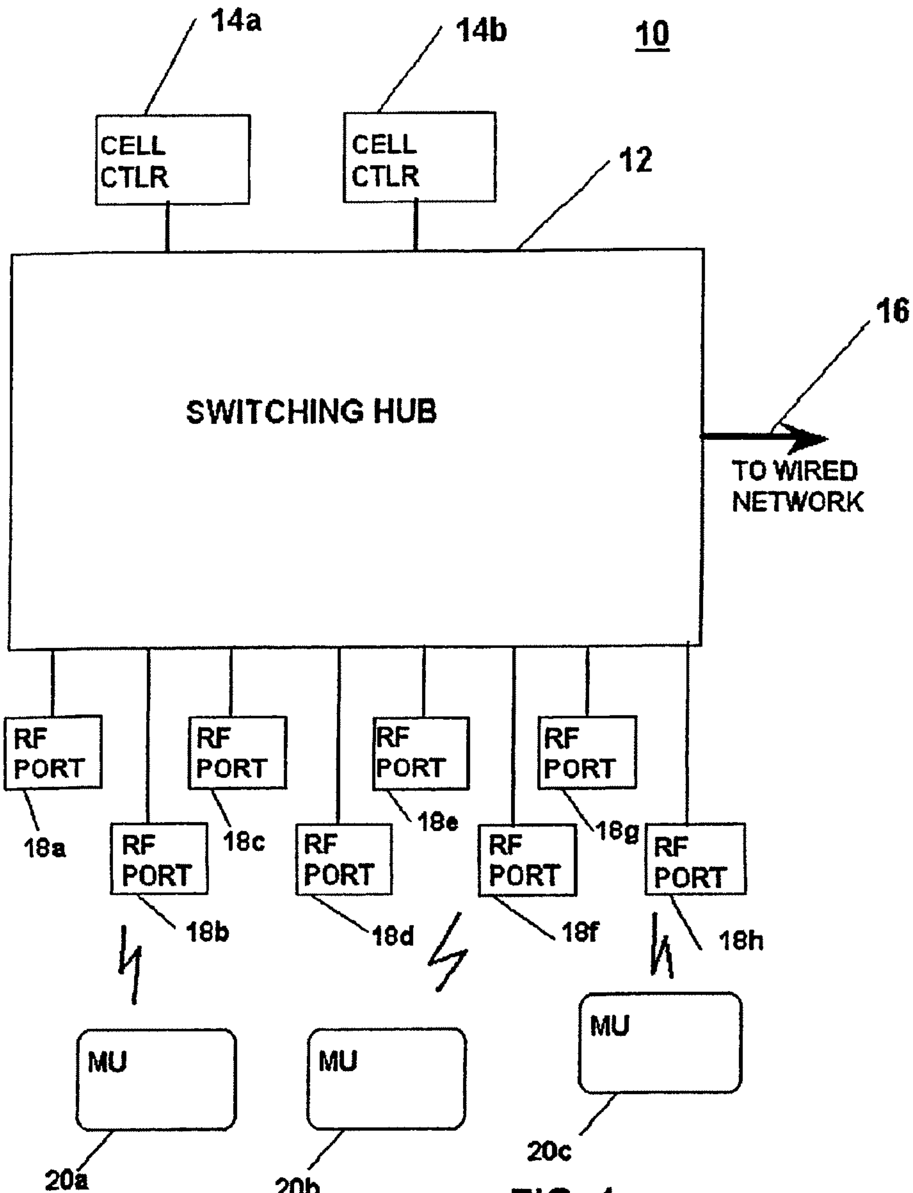

14a
14b
10
CELL CTLR
CELL CTLR
12
16
SWITCHING HUB
TO WIRED NETWORK
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
RF PORT
18a
18b
18c
18d
18e
18f
18g
18h
MU
MU
MU
20a
20b
20c

FIG. 1

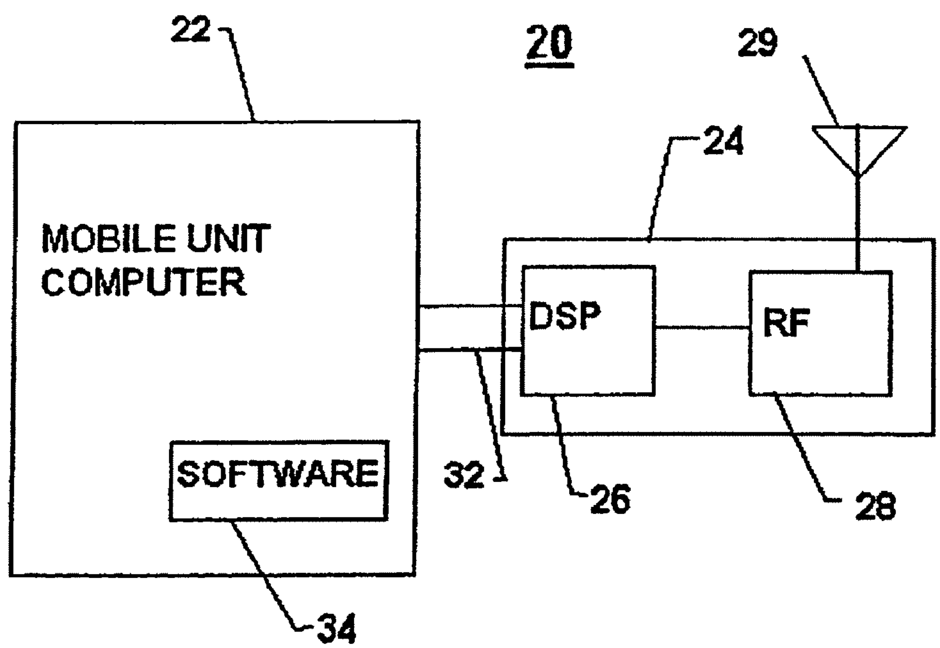


FIG. 2

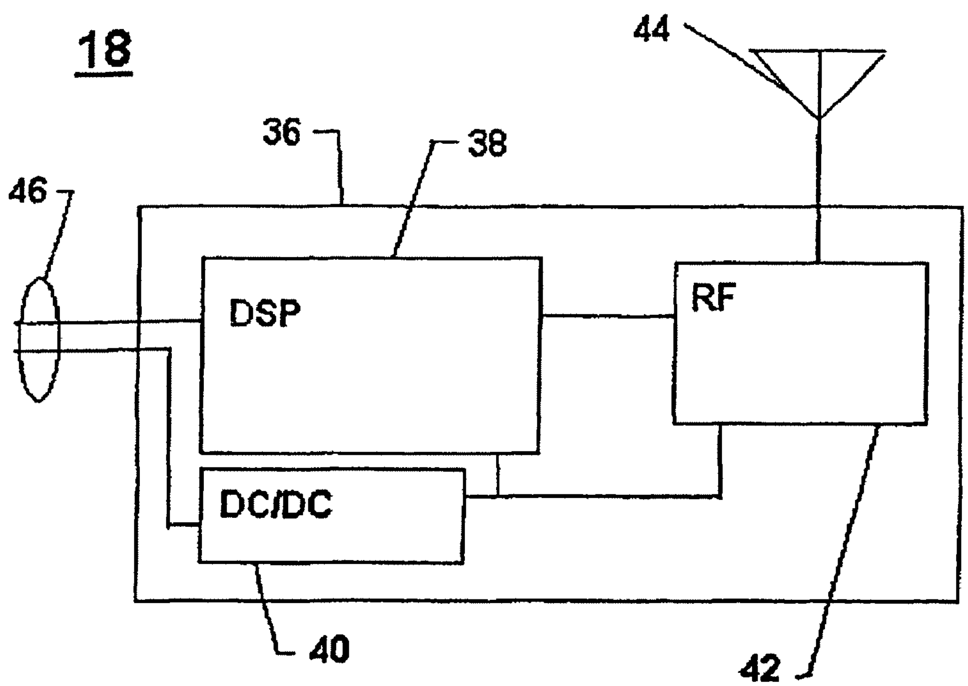


FIG.3

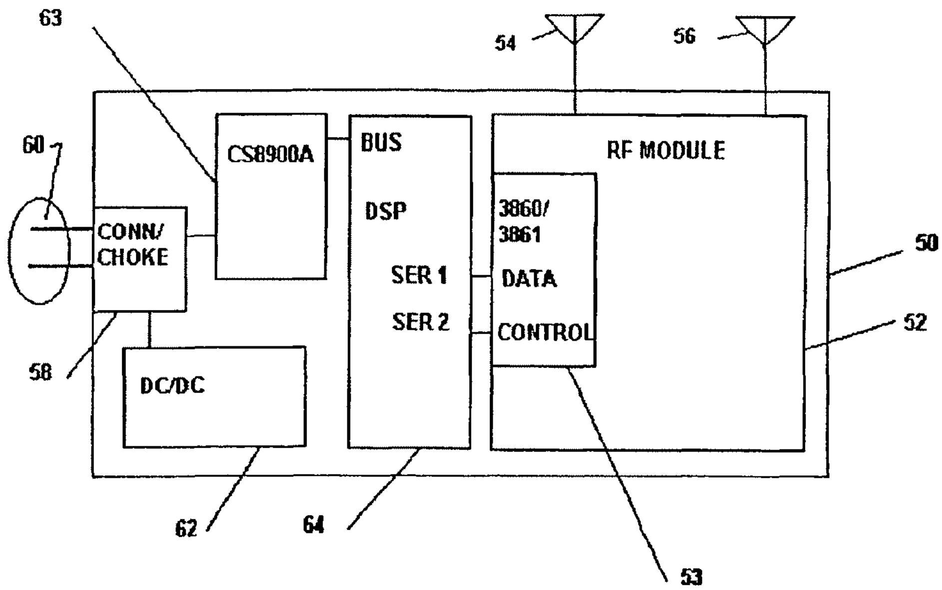

63
54
56
60
CS8900A
BUS
RF MODULE
DSP
3860/
3861
CONN/
CHOKE
SER 1
DATA
50
SER 2
CONTROL
52
58
DC/DC
62
64
53

FIG. 4

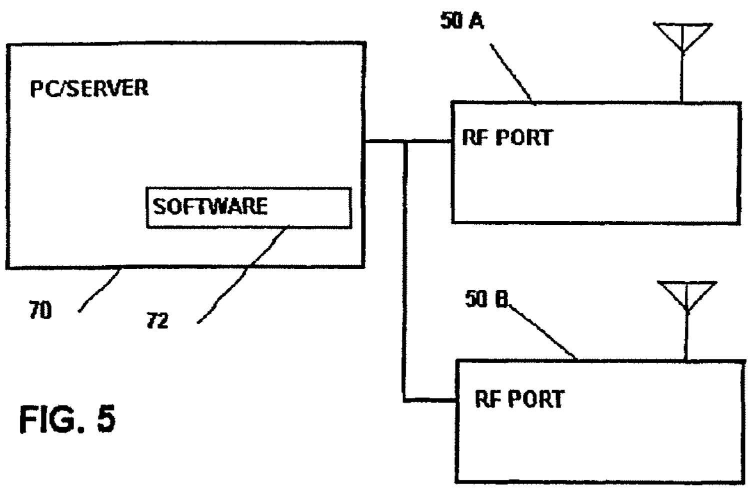

50 A
PC/SERVER
RF PORT
SOFTWARE
70
72
50 B
RF PORT

FIG. 5

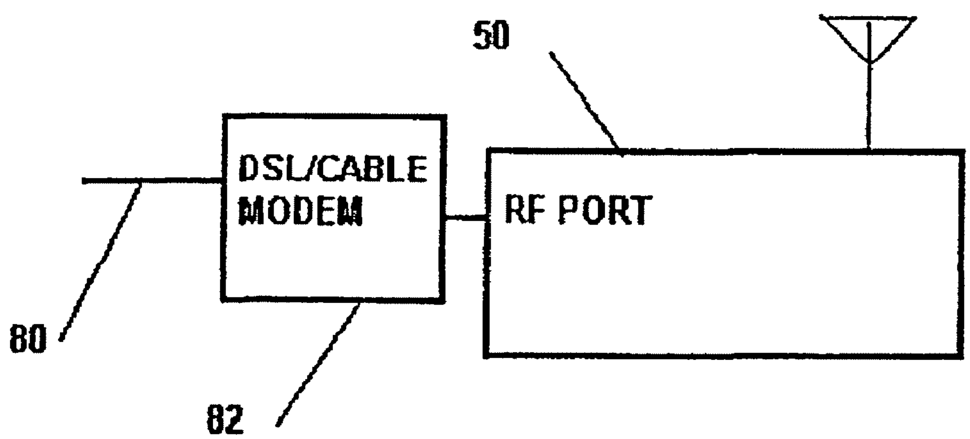


FIG.6

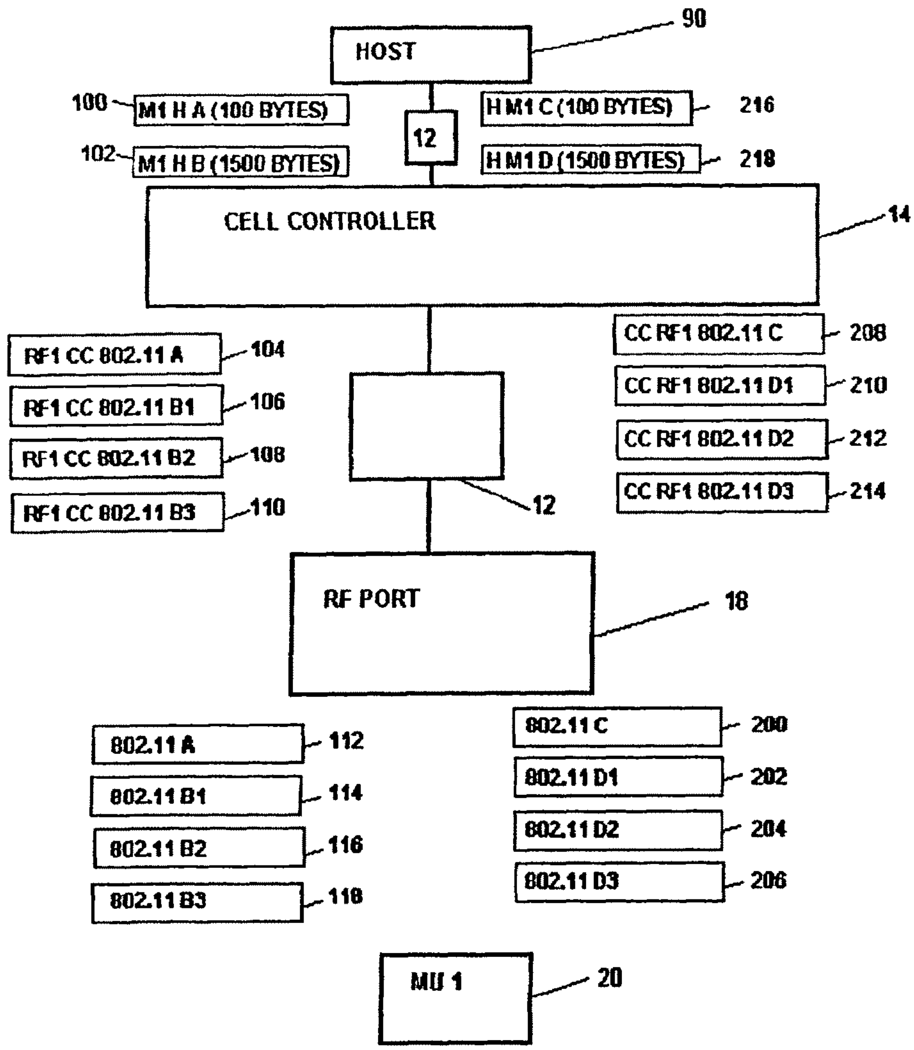
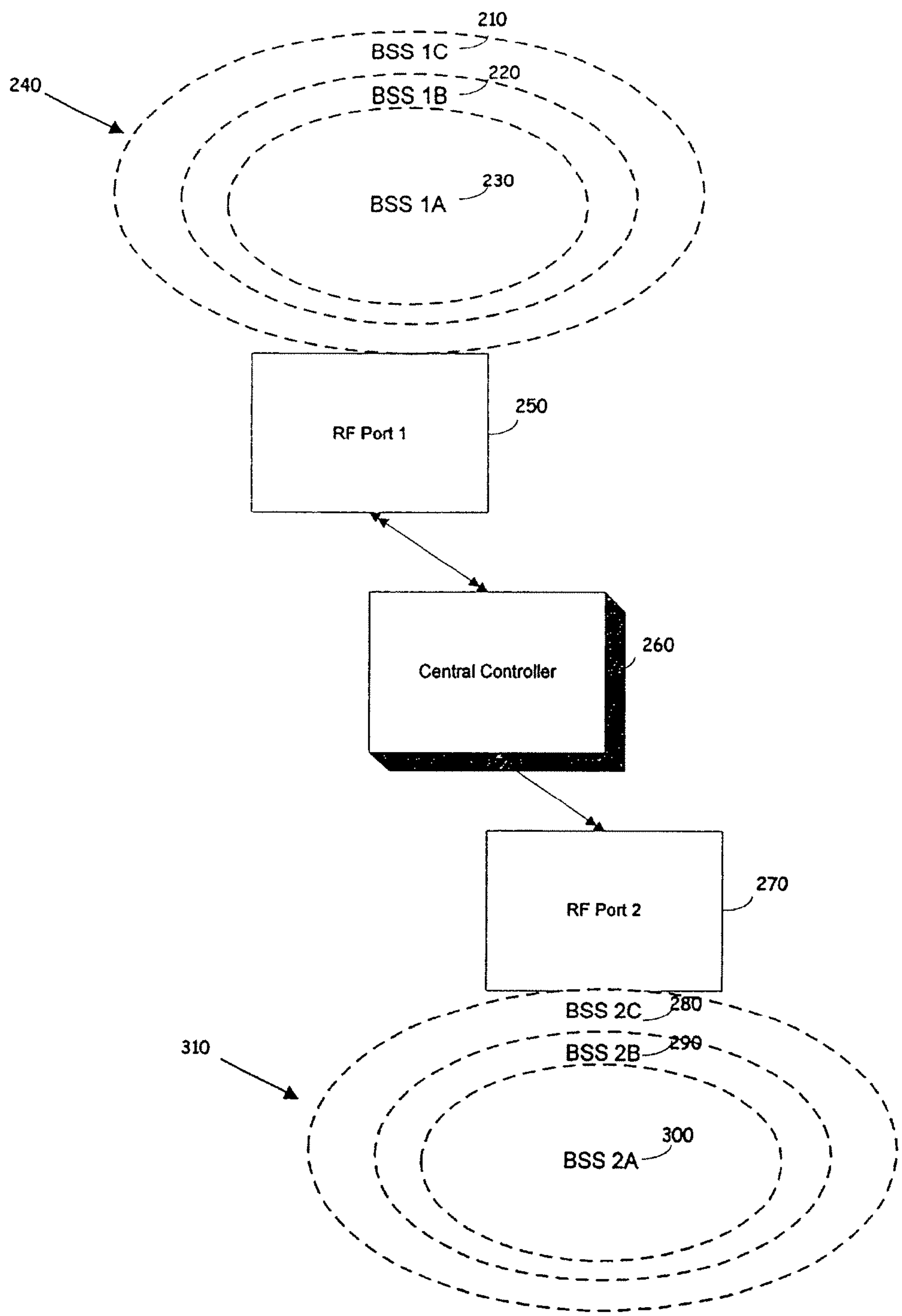

HOST
90
100
M1 H A (100 BYTES)
102
M1 H B (1500 BYTES)
12
H M1 C (100 BYTES)
216
H M1 D (1500 BYTES)
218
CELL CONTROLLER
14
RF1 CC 802.11 A
104
RF1 CC 802.11 B1
106
RF1 CC 802.11 B2
108
RF1 CC 802.11 B3
110
CC RF1 802.11 C
208
CC RF1 802.11 D1
210
CC RF1 802.11 D2
212
CC RF1 802.11 D3
214
12
RF PORT
18
802.11 A
112
802.11 B1
114
802.11 B2
116
802.11 B3
118
802.11 C
200
802.11 D1
202
802.11 D2
204
802.11 D3
206
MU 1
20

FIG. 7

FIG. 8



210
BSS 1C
220
BSS 1B
240
230
BSS 1A
RF Port 1
250
Central Controller
260
RF Port 2
270
BSS 2C
280
BSS 2B
290
310
300
BSS 2A

SECURITY IN MULTIPLE WIRELESS LOCAL AREA NETWORKS

REFERENCE TO PRIOR APPLICATION

This application is a continuation-in-part of pending application Ser. No. 09/780,741, filed Feb. 9, 2001, which is a continuation-in-part of pending application Ser. No. 09/528,697, filed Mar. 17, 2000.

BACKGROUND OF INVENTION

This invention relates to wireless data communications networks, and in particular to arrangements for communications between mobile data handling units and a central computer using wireless data communications.

The assignee of the present invention supplies a wireless data communications system known as the Spectrum 24 System, which follows the radio data communications protocol of IEEE Standard 802.11. In the system as implemented, mobile units are in data communication with a central computer through access points. The access points may communicate with a central computer or computers over a wired network. Each of the mobile units associates itself with one of the access points. The access points in this system are functional to perform all the implemented requirements of the standard protocol, including, association and roaming functions, packet formulation and parsing, packet fragmentation and re-assembly encryption and system access control. In order to maintain order and reduce radio communications each access point must determine which of the data communications received over the wired network from the central computer is destined for a mobile unit associated with that particular access point. This requirement adds significant computational capacity to the access point, increasing the cost thereof.

In addition, in applications that must support a high volume of data communications from multiple users, such as systems supporting a self-service shopping system, hospital systems, systems that include paging or voice data links to many users, or systems supporting communicating with electronic shelf labels, additional access points are required to support the data communications traffic, increasing the overall system cost.

The cost of an operational access point is dependent not only on the complexity thereof and the requirement for high speed processing of data pockets for purposes of selecting those destined for mobile units associated with an access point, but the additional cost of the installation of electrical power to the location of the access point, and the cost of a power supply to convert AC electrical power to DC power for the circuits of the access point. Further cost may be involved in physically mounting the access point hardware and antenna.

In prior systems each access point is connected on an Ethernet wired network to the central computer. The access points are required to determine the identity of mobile units which have become associated with them and to extract from the data packets on the Ethernet network those packets addressed to a mobile unit associated with the access point. This requirement has led to significant processing burden for the access points and led to increased cost for the access points.

In the system described in my prior published International Patent Application WO 099 37047, published Jul. 22, 1999, the central computer communicates over an Ethernet wired network with an intelligent switching hub. Alternately a token ring network can be used. The switching hub determines the destination of each packet and routes packets to an access point if the destination of the packet is a mobile unit associated with the access point. To achieve this function, the hub is an intelligent hub which maintains a routing list of mobile units and their associated access point according to the port of the hub.

In practice, the hub need only maintain a source list for those access points connected to the hub and mobile units associated with the access points connected to the hub. Thus, if a packet is received at a hub over the Ethernet with a destination address which is not associated with that hub, the packet is ignored. The hub will route the packet to an access point only if the destination address of the packet is identified on the list. When a packet is received on a hub port associated with a communications line connected to an access point, the source address is associated with the hub port in the list. The packet is routed either to the Ethernet connection or to another port according to the destination address.

By determining destination address in the hub and maintaining the association of a mobile unit address with an access point connected to a port of the hub in a routing list of the hub, the functionality required of the access points is greatly reduced. The access point acts merely as a conduit sending RF transmissions of packets received on its communication line, and receiving transmissions from associated mobile units and providing Ethernet packets to the hub. In addition, the access point must provide mobile unit association functions and other 802.11 protocol functions, as provided in the Spectrum 24 system, and may also provide proxy polling responses for associated mobile units that are in power saving mode.

The prior system may have a large number of access points, each with a memory containing program instructions for carrying out the various required functions. This distribution of processing makes it difficult to upgrade a system or to provide changes in system configuration because any upgrade or change may require changes to the program code in each of the access points. Such distribution of processing functions also makes system management functions, such as load balancing or access control more difficult.

It is therefore an object of the present invention to provide an improved wireless data communications methods and systems having lower cost, to enable the economical provision of reliable wireless data communications with increased capacity in complex installations or at reasonable cost or simple installations.

SUMMARY OF THE INVENTION

In accordance with the invention there is provided a system for providing wireless data communications between mobile units and a wired network. The system includes a plurality of RF ports having at least one data interface and arranged to receive formatted data signals at the data interface and transmit corresponding RF data signals and arranged to receive RF data signals and provide corresponding formatted data signal. There is also provided at least one cell controller, arranged to receive data signals from the wired network and to provide formatted data signals corresponding thereto and to receive formatted data signals and to provide data signals corresponding thereto to the wired network, the cell controller controls association of mobile units with one of the RF ports, provides formatted data

signals for said mobile units to an associated RF port and receives formatted data signals from the mobile unit from the associated RF port.

In accordance with the invention there is provided an improvement in a wireless data communications network coupled to a data processing system, having a plurality of RF ports and mobile units, wherein the mobile units associate with one of the RF data communications ports to conduct data communications with said data processing system. The mobile units are assigned to one of the RF ports by a cell controller, and the cell controller is arranged to receive first data communications from the data processing system and to relay the data communications to an assigned RF port and to receive second data communications from the RF ports and relay the second data communications to the data processing system.

In accordance with the invention there is provided a method for operating a wireless local area network having at least one RF port, a plurality of mobile units and a cell controller coupled to the RF port. The RF is operated port to relay signals received from mobile units to the cell controller and to relay signals received from the cell controller to the mobile units. The cell controller is operated to control association of the mobile units with the RF port, including sending and receiving association signals between the RF port and the cell controller, and to send messages to and from the mobile unit via the RF ports.

In accordance with the invention there is provided an improvement in a mobile unit for use in a wireless data communications system, wherein the unit has a data processor and programs for the data processor and a wireless network adapter having a programmed processor and a radio module. The programmed processor performs first communications processor functions including control of the radio module and the data processor operates under the programs to perform second communications processor functions, including association with a radio access location of the wireless data communications system.

According to the invention there is provided an improvement in a wireless data communications system for providing data communications following a standardized protocol. wherein the protocol includes association of mobile units with radio access locations. At least one RF port is provided at a radio access location, which RF port comprises a radio module and an RF port processor in data communications with a programmed computer. The RF port processor performs first functions of the standardized protocol and the programmed computer performs second functions of the standardized protocol, including the association of mobile units with said radio access location.

According to the invention there is provided an RF port for use in a wireless data communications system comprising a radio module having a data interface and a transmitter/receiver for wireless data communications; and a digital signal processor having first and second data communications ports, random access memory and read-only memory. The second data communications port is coupled to the data interface of said radio module. The read-only memory is provided with a bootloader program for controlling the digital signal processor to load program instructions to the random access memory via the first communications port. According to the invention there is provided a method for operating an RF port having a radio module, a digital processor, random access memory and read-only memory. A bootloader program is stored in the read-only memory. The digital processor is operated to download instructions from a computer to the random access memory using the bootloader program and the RF port is operated under the downloaded instructions to send and receive messages using the radio module.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having a wired network interface, a data processor and an RF module. Signals are provided to the wired network interface having wireless address data and message data within a data packet addressed to the RF port using a protocol for the wired network. The processor is operated to provide wireless data signals having the wireless signal format for the address data and the message data to said RF module and operating the RF module is operated to transmit the wireless data signals as an RF signal modulated with the wireless signal format.

According to the invention there is provided a method for transmitting signals having a wireless signal format using an RF port having an Ethernet interface, a data processor and an RF module. An Ethernet data packet is provided to the Ethernet interface, the Ethernet data packet encapsulating as data a data message having the wireless signal format. The data processor is operated to provide the data message to the RF module. The RF module is operated to transmit the data message as an RF signal.

According to the invention there is provided a method for receiving signals having a wireless signal format including wireless address data and message data at an RF port having a wired network interface, a data processor and an RF module. The RF module is operated to receive RF signals having the wireless signal format. The data processor is operated to receive wireless data signals from the RF module and provide data signals to the wired network interface comprising a data packet having a source address corresponding to the RF port using a protocol for the wired network, the data packet including the wireless address data and the message data.

According to the invention there is provided a method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port having an Ethernet interface, a data processor and an RF module. The RF message signals are received in the RF module and provided as data signals to the data processor. The data processor is operated to interpret address data in the data signals and, in dependence on the address data, said message data and said address data is encapsulated in an Ethernet packet, which is provided to the Ethernet interface.

In accordance with the invention there is provided a simplified wireless local area network system including a computer having a data processor and a memory, an RF port having an RF port data processor, an RF module and a data communications interface coupled to the computer. A first program is provided in the memory of the computer for operating the computer data processor to perform first wireless data communications functions, including association with mobile units. A second program is provided for operating the RF port data processor to perform second wireless data communications functions.

According to the invention there is provided a wireless access device for providing wireless access to a communication system. The device includes a modem for sending and receiving data messages on the communications system and an RF port, having a data interface coupled to the modem, a data processor and an RF module. The data is programmed to receive data messages from the modem, to format the messages for wireless data communications and to provide the formatted messages to the RF module for transmission

by RF data signals to at least one remote station, and to receive RF data signals from the at least one remote station, and to provide data messages to the modem to be sent on the communications system.

According to the invention there is provided a method for providing wireless access to the Internet. A modem having a data communications interface connected to an RF port is connected to the Internet. The RF port is configured for wireless data communication to at least one mobile unit having a predetermined wireless communications address. A mobile unit configured with the predetermined wireless communications address is provided for conducting RF data communications with the RF port. The RF port is arranged to relay communications between the mobile unit and the modem.

The apparatus and methods of the present invention provide RF ports as radio access locations which are less expensive than known access points and provide greater system management and flexibility. Much of the software used for controlling communications to and from mobile units is performed in a controller wherein software upgrades and changes are easily implemented. According to some embodiments, wherein instructions are downloaded to RF ports, it becomes easy to upgrade RF port instructions. System control is centralized, making management easier and enabling changes to access control and encryption functions. Priority for traffic purposes can also be established to facilitate digital telephony by giving priority to voice traffic. Accordingly, a system is provided that has significant flexibility using common RF port hardware to provide a wireless LAN having from one to hundreds of radio access locations.

According to the invention, the same RF port may provide multiple ESS identifications such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security.

For a better understanding of the present invention, together with other and further embodiments thereof, reference is made to the following description, taken in conjunction with the accompanying drawings, and its scope will be pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a wireless communications system in accordance with the present invention.

FIG. **2** is a block diagram illustrating one example of a mobile unit arranged to be used in the system of FIG. **1**.

FIG. **3** is a block diagram illustrating one example of an RF port for the system of FIG. **1**.

FIG. **4** is a more detailed block diagram of a preferred embodiment of an RF port in accordance with the invention.

FIG. **5** is a block diagram of an arrangement of a computer and RF port for providing a simplified wireless local area network according to the present invention.

FIG. **6** is a block diagram of an arrangement for providing wireless access to the Internet using the RF port of the present invention.

FIG. **7** is a diagram showing signal format according to one embodiment of the invention.

FIG. **8** is a diagram showing an compilation of RF ports having multiple ESS arrangements for providing overlapping, multiple wireless networks.

DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, there is shown an example of a wireless data communications system **10** according to the present invention for providing data communications between a central computer or a collection of computers on a wired network **16** and a plurality of mobile units **20**. While prior systems used access points at each radio access location, where the access points are capable of managing wireless communications with mobile units, the system of FIG. **1** uses simplified RF ports **18** at each radio access location to provide radio packet communications with the mobile units **20** using a wireless communications protocol, such as EEEE Standard 802.11, whereby the radio modules in the mobile units **20** monitor polling signals from the RF ports **18**, which are originated by the cell controllers **14** and associate with an RF port **18** for purposes of data communications. The system arrangement of FIG. **1** is especially effective in a large wireless local area network (LAN) system wherein it may be necessary to provide a large number of radio access locations. Typically such systems, operating at low power microwave frequencies, require radio access locations at about every 100 feet. Where the wireless LAN system must operate with mobile units, for example, portable computers or similar devices, located throughout a large facility, such as a business, hospital complex or university campus, many such radio access locations may be required, possibly several hundred. Accordingly there is an incentive to reduce the cost of the installation at each radio access location. According to the present invention the system configuration and operation are redesigned to reduce the cost of each individual radio access point. In addition, the system of the present invention provides a concentration of operational control in one or more central controllers **14**, making management of the system easier and making modifications and upgrades easier to install.

According to the invention, much of the functionality of the 802.11 protocol associated with the conventional access point, is removed from the device located at the radio access location and provided in a cell controller **14**, which may be located in conjunction with a switching hub **12**, connected to the wired network **16**, with which the wireless network **10** is associated. In particular the usual "access point" device is replaced with a simpler device **18**, herein referred to as an "RF port" which contains the RF module, which may be the same RF module used in the prior art access point, and simplified digital circuits to perform only a limited portion of the 802.11 media access control (MAC) functions performed by the prior art access point. In particular the RF port **18** preferably performs only functions of the access point that require a lower level of processing resources in terms of processor capacity and software complexity (memory requirement), and which are time critical. Other functions that are more processor intensive and require more complex programming, and which are not time critical, are relegated to one or more "cell controllers" **14**, which may perform these more complex functions for a plurality of RF ports **18**.

In order to perform the higher level processing functions of the access point in the cell controller **14**, according to the present invention, all messages directed to or from mobile units **20** associated with a particular RF port **18** are processed in a cell controller **14**. A system may have one or more cell controllers, which may comprise, e.g. Pentium-type board level computers, each of which is arranged and programmed to handle data message traffic and mobile unit associations for a selected plurality of RF ports **18**. A

switching hub **12** may be interposed to provide message switching among the wired network connected to communications line **16**, RF ports **18** and cell controllers **14**. Each of the one or more cell controllers **14** acts as a virtual "access point" for traffic addressed to its associated RF ports **18** and to the mobile units **20** associated with those RF ports. When a message is addressed to a mobile unit **20** is received on line **16**, switching hub **12** directs the message to the appropriate cell controller **14**, which reformats the message and relays the message to the appropriate RF port **18**, again through switching hub **12**. When the message is received by an RF port **18**, it is converted to a radio message and sent to the mobile unit **20** with a minimum of processing.

Likewise, when a message is received from a mobile unit **20** by an RF port **18**, it is converted to a digital message packet and relayed to the cell controller **14** associated with the RF port **18** through the switching hub **12**. The cell controller **14** parses the message for further relay in the system.

An important feature of a preferred embodiment of the invention is the fact that mobile unit association with the RF ports **18** is a function handled by the cell controller **14**. Accordingly, when a mobile unit **20** first becomes active, it sends an association request signal in response to a beacon signal sent by an RF port **18** (in response to direction by the cell controller). The association request signal is relayed by the RF port **18** to the cell controller **14**, which performs the processing required for association, including consideration of RF port loading. Cell controller **14** generates appropriate response signals to be sent by the RF port **18** to the mobile unit **20**. The cell controller **14** is in an appropriate position to evaluate the loading of the RF ports **18** under its control, and may therefore easily perform load leveling functions, for example, by providing a message to RF port **18** accepting or declining an association request. In addition, the cell controller **14** may receive load messages from other cell controllers **14** in the system **10** and thereby coordinate overall load management. As a mobile unit **20** moves from a location serviced by one RF port **18** to a location serviced by a different RF port **18**, the cell controller **14** receives information from the mobile unit **20** indicative of its reception of beacon signals from the various RF ports in the system and performs the necessary functions to support roaming of mobile unit **20**.

While in the system **10** of FIG. **1** the cell controllers **14** are shown as separate computers connected to switching hub **12**, the term "cell controller" is intended to refer to the logical functions performed by these computers rather than the computers themselves. As will become apparent, the cell controller may be implemented in a variety of ways other than as shown in the exemplary system **10** of FIG. **1**.

Implementation of a simplified RF port is achieved by performing "higher level" functions of the 802.11 protocol Media Access Control (MAC) in the cell controller and performing "lower level" functions in a simplified RF port.

The lower level functions are those that are hardware intensive and often time critical. The higher level functions are those that are software intensive and not time critical. One possible division of the exemplary 802.11 MAC functions is as follows:

- Lower Level Functions (preferably to be performed at RF port)
  - Cyclic Redundancy Check (CRC)
  - Network Activity Vector (NAV)
  - Ready to Send/Clear to Send (RTS/CTS)
  - Header generation/parsing
  - Collision Avoidance
  - Frequency Hopping
  - Ack parsing/generating
  - Retransmission timeout
- Higher Level Functions (preferably to be performed at Cell Controller)
  - Association processing
  - Roaming
  - Retransmission
  - Rate Control
  - Host Interface

The following optional (higher or lower) level MAC functions can be placed in either the higher or lower level categories.

- Wired Equivalent Privacy encryption/decryption (WEP)
- Fragmentation/Reassembly
- Data Movement
- Power Save Polling Support (PSP)

According to a preferred arrangement of the system of the invention, the lower level MAC functions are provided at the RF port, the higher level MAC functions are provided in the cell controller and the optional level functions can be provided at either the cell controller or the RF port.

A major advantage of the invention is a cost savings in hardware, processor capacity and storage capacity for the RF port. Since a system with, for example, one hundred or more radio access locations may be implemented with one or two cell controllers, the processor hardware and memory required for the higher level MAC functions need be provided only at the cell controllers. In fact, the capabilities of the overall system, for WEP encryption and other special functions, can be increased at modest cost by using a high performance board level personal computer or even a host computer as a cell controller.

By eliminating the higher level MAC functions from the radio access locations, the cost of the devices installed at those locations can be significantly reduced because of lower processor capacity and storage.

In connection with association and roaming functions the RF ports **18** provide beacon signals in response to commands generated by the cell controller **14**. When an association sequence is initiated by a mobile unit, the RF port **18** relays the association messages between the mobile unit **20** and the cell controller **14** during the association process, which is handled by the cell controller **14**.

In connection with message traffic to a mobile unit **20** from a network processor, message packets are routed by switching hub **12** to the cell controller **14** responsible for the mobile unit **20** addressed. The message is buffered and formatted by the cell controller **14** and in a preferred arrangement encapsulated by the cell controller **14** as a mobile unit packet within a wired network packet addressed to the responsible RF port **18**. This packet is routed to the RF port **18**. The RF port **18** extracts the mobile unit packet from the message and sends the packet to mobile unit **20** as a radio signal. The RF port **14** may also provide a CRC calculation and generate CRC data to be added to the message. The mobile unit **20** responds with an acknowledgment signal to the RF port **18**, which generates and sends an acknowledgment status message to cell controller **14**.

In connection with messages for systems connected to the wired network **16**, the mobile unit **20** sends a packet to the RF port **18** by radio signal. The RF port **18** filters received radio message packets according to the BSS (Basic Service Set) identifier in the packet and, if the packet has a BSS identifier associated with the RF port **18**, performs the CRC

check as the packet is received. The RF port **14** then generates and sends an acknowledgment signal to the mobile unit **20** and sends the received packet to cell controller **14**. Cell controller **14** buffers, parses and, if necessary, decrypts the packet and routes the packet to the host on network **16** through hub **12**.

The arrangement of RF port **18** maybe identical to current access points used in the Spectrum 24 system with some of the access point software non-functional. Preferably the RF ports are simplified to reduce cost and power consumption. To reduce installation expenses the RF ports are powered via an Ethernet cable, which also connects RF ports **18** to switching hub **12** or to cell controller **14**. The RF ports can be arranged in a small package (e.g. portable radio size) with integrated diversity antennas and arranged for easy mounting, such as by adhesive tape or Velcro. Connection to the switching hub **12** is by Ethernet cable which is also provided with D.C. power, such as by use of a choke circuit, such as Pulse Model PO421 as described in my referenced International Application. The choke circuit may be built into an Ethernet connector and is available in this configuration.

The RF port **18** does not have to perform Ethernet address filtering and does not have to perform 802.11 association and roaming functions and can therefore have a lower level of processor capacity, software support, memory and power consumption. In one embodiment shown in FIG. **3** the RF port **18** includes only a digital signal processor (DSP) **38** which includes internal RAM and ROM. The DSP **38**, which may be one of the Texas Instruments TMS 320 family of DSP processor, such as the 5000 series, specifically the TMS 320 UC 5402 or the TMS 320 VC 5402. This DSP provides an interface between the Ethernet cable **46** and the RF module **42** in RF port **18**, as shown in FIG. **3**. The RF module **42** is provided in housing **36** with DSP **38**, DC/DC power supply **40** and carrying one or more antennas **44**. RF module **42** includes a 3860 or 3861 baseband processor, such as HFA 3860B, to interface with the digital portion of the RF port **18**, specifically DPS **38**. In one arrangement the ROM memory of the DSP **38** can be provided with "bootloader" firmware that downloads the necessary DSP software instructions from the cell controller **14** upon startup of the RF port **18**, and loads the instruction into the RAM of the DSP **38**.

The processors that are currently preferred as a possible lower level MAC engine are the TMS320UC5402 and the TMS320VC5402. These parts are functionally identical except for differences in power consumption (the VC5402 is currently in production and while the UC5402 is still being sampled). The basic configuration of the UC5402/VC5402 is:

- 100 MIPS execution rate
- 8 KB on chip ROM (organized as 4K×16 bits)
- 32KB on chip RAM (organized as 16K×16 bits)
- Two 16 bit timers with 1 μs or better resolution
- Two High speed, full duplex serial ports (up to 50 Mbits/sec each) with smart DMA channel support
- One High speed 8 bit wide host/parallel port (160 Mbit/sec)
- Six DMA channels for general purpose use
- 16 bit external memory/IO Bus with internal wait state generation
- 16 interrupts with 3 instruction (30 ns) worst case latency
- 0.54 mW/MHz power consumption (30 mA@1.8 v at 100 MHz)
- Low Power Modes (6 mA, 2 mA, 2 μA depending on setting)
- Internal PLL that generates the system clock with an external crystal

This section will describe the use of a 5402 DSP **38** as a MAC engine for 11 Mbit/sec 802.11 DS systems. It could clearly be used in FH systems as well. We will focus on the how the 5402 interfaces to the Intersil 3860/1 baseband processor in RF module **42** and how it implements the lower level MAC functions.

The first issue is how the 5402 DSP **38** interfaces to the 3861 (much of what is said applies to the 3860 as well) and the rest of the RF module **42**. As shown in FIG. **4**, the 3861 processor **53** in RF module **52** of RF port **50** has 2 major interfaces, both serial. The first interface, labeled DATA, is used to transfer data between the MAC engine comprising DSP **64** and the 3861. It has four lines: TxD, TxC, RxD, and RxC and operates at up to 11 Mbits/sec. The exact rate depends on the transfer rate of the packet. The clock signals of both interfaces are generated by the 3861 and so transfers are controlled by the 3861. Both can be halted at any time by the 3861 as well as change rate. The second serial interface, labeled CONTROL is used to load commands into the 3861 and read status information from the 3861. This interface is a 4 wire bi-directional interface using one data line, one clock line, one "direction control" line, and a chip select line. This serial interface also can operate at up to 11 Mbits/sec. In addition to the serial interfaces, there are additional control and status lines such as Reset, TX_PE, RX_PE, TX_RDY. etc.

The 5402 DSP **38** has two sets of full duplex serial interfaces that are capable of operation up to 50 Mbits/sec (given a 100 MHz clock). They can be clocked using internal or external sources. In this design one of the sets of serial interfaces, labeled SER1, is used to connect to the high speed data lines of the 3861 interface **53**. The 5402 DSP **38** interfaces have the same basic lines (RxD, RxC, TxD, TxC) as does the 3861 and so they connect with minimal trouble. Although the 5402 uses 1.8 v for its core, its I/O lines are 3.3 v tolerant and so can interface to the 3861 without converters. In addition, they are fully static and so can deal the start/stop operation of the clock lines from the 3861.

Data transfer will be done under DMA control within the 5402 using what TI calls "Auto Buffering Mode." This provides essentially dedicated DMA channels for each serial port interface (two DMA channels per serial port interface). These channels access an independently operating bank of SRAM and so transfers have no impact on CPU performance. The CPU can start transfers in either direction and be notified via interrupt on their completion.

Interfacing to the control serial port on the 3861 interface **53** can be done in three different ways. The first, illustrated in FIG. **4**, utilizes the second serial port, labeled SER 2 on the 5402 DSP **64** with a small amount of combinatorial logic/buffering to convert between the single data line of the 3861 and the dual data lines of the 5402. Another approach is to use an external shift register that would perform serial/parallel conversion. This register would sit on the I/O bus of the 5402 and would be loaded/read by the 5402 and data shifted between it and the 3861. The third approach is to use an external buffer/latch on the 5402 I/O bus and "bit bang" the clock/data lines to the 3861. The second or third approaches free up the second serial channel for more other use such as providing high speed serial interfaces such as Ethernet or USB and in some applications would be preferred over the first. All require a small amount of external combinatorial logic and so the cost of all solutions is about the same.

The same logic would apply to interfacing to the synthesizer. It is accessed even less often than the control port of the 3861 and so a "bit banging" approach would work fine.

Finally, interfacing to the various control and status lines presented by the 3861 can be done via simple bidirectional register/latch connected to the I/O bus of the 5402. The 5402 can read/write this register as it needs to control and monitor the 3861. It would be possible to combine all control/monitor functions (including the serial control interface) into a single 16 bit buffered register latch. Parallel control/status lines would be connected to particular lines of this latch. Serial control interfaces would also be connected and "bit banged" as necessary to move data between the 5402 and 3861.

The arrangement shown in FIG. **4** uses a Crystal CS 8900 A Ethernet controller **63** coupled to the parallel port of DSP **64** to interface to the Ethernet port **58**. An Ethernet connector/choke **58** receives cable **60** and provides DC power from cable **60** to DC/DC power supply **62**. The FIG. **4** RF port **50** includes spaced diversity antennas **54**, **56** to improve reception in multipath conditions.

A premise of this design is that the TI DSP is capable of implementing all lower level MAC functions without external hardware assistance. This, of course, is the most demanding model but we will find that the 5402 is up to the task. The most computational demanding tasks are the CRC-32 and WEP processing. The CRC-32 calculation is performed over the entire packet and must be completed in time to generate an ACK should the CRC turn out to be correct (or to attach the calculation result to an outgoing packet on transmission). This means that the CRC calculation must be performed in near real-time during packet transfer between the 3861 and 5402. TI has shown in an application note that a CRC-32 calculation can be made by a 5000 series DSP in 13 instructions. At 100 MIPS this is about 130 ns. At 11 Mbit/sec, a byte takes about 770 ns to transfer and so we have plenty of time to do the CRC. When receiving a packet, the serial port would be transferring the data from the 3861 to SRAM within the 5402. At the same time the CPU within the 5402 would be reading each received byte from SRAM and calculating the CRC. It would of course have to make sure that it did not overrun the receive buffer, but that would be a relatively simple task. Much the same process would happen during transmission. In either case, the CPU has lots of time to do the CRC.

The WEP processing if performed in the RF port **50**, is a harder function to perform than CRC-32 since it includes both an RC4 encryption function and a second CRC-32. At the same time it does not need to be completed prior to ACK generation/reception nor is performed on every packet (just data packets). The RC4 encryption function consists of two parts: building the encryption table (a 256 byte table) using the selected key and doing the encryption/decryption process. Based on sample code, it is estimated that building the table would require about 1200 instructions (12 ms at 100 MIPS) and the encryption/decryption process would require about 12 instructions/byte. There is no difference in this cost for 40 or 128 bit keys. The WEP CRC-32 would require another 13 instructions per byte.

The per byte computational burden for WEP would thus be about 25 instructions or about 250 ns at 100 MIPS. When added to the packet CRC-32, the total load would be around 38 instructions/byte. As we pointed out, at 11 Mbit/sec we have about 77 instructions/byte available, so we are spending about 50% of the CPU on CRC/WEP tasks. The biggest issue is the 1200 clocks (12 us) required to build the encryption table during receive (For transmission, the calculation can be done prior to starting packet transfer). Pausing to create the table would put the CPU about 18 bytes (12 us at 770 ns/byte) behind in the CRC/WEP/CRC calculation process. It would require about 40 data bytes to catch up (1200 clocks/30 extra clocks per byte) in both packet CRC and WEP/CRC functions. Since the minimum TCP/IP header is at least 40 bytes (plus any user data), we should have enough time. In any case if we are a little late in WEP/CRC calculation, no harm is done. An alternative approach would be to catch up first for the packet CRC calculation and then catch up with WEP/CRC.

After CRC and WEP/CRC processing, the next most critical activity is header parsing on receive and generation on transmit. This is because of the need to identify packets for the station and generate appropriate responses. On receive, the processor must parse two or three 48 bit addresses and at least a 16 bit header command field. After the packet completes, an ACK may need to be generated.

The 5402 can easily handle these functions. Since these functions are performed prior to WEP processing, the CPU has 64 instructions/byte (77—13) to perform these functions. Since many of them can be performed on a 16 bit or even 32 bit basis (the 5402 supports both 16 and 32 operations), there may be up to 128 or 256 instructions per data item (i.e. 256 instructions to perform a 32 bit address check). These functions are performed at 2 Mbit using a 1 MIPS 188 CPU. We have a 100 MIPS CPU to do the same tasks at 11 Mbit/sec.

ACK generation is likewise relatively simple. An ACK frame is only 14 bytes long, including the 4 CRC-32. Given there is a long (80 us) preamble, we have 8000 instructions to prepare the ACK. The same applies to RTS/CTS exchanges.

There are two 16 bit timers available on the 5402. In this model, one would be used for TSF timing and the other for all other functions. There are really only a few other timer functions: NAV, Retransmission, collision avoidance slot countdown, etc. Retransmission and collision avoidance activities go on only when waiting for an ACK or to start a retransmission after detection of an idle network. In such cases there is no data transfer going on and so there is lots of CPU cycles available.

Support for MU PSP function can be done in a variety of ways, depending on how much, if any, external hardware is provided. The 5402 provides a variety of means of conserving power. The first is simply to slow down the CPU clock via the software controlled PLL within the unit. The 5402 generates internal clocks via a PLL that is driven by either an external crystal or clock. The PLL multiplies the base frequency of the crystal/external clock by a factor determined by software. Hence one means of controlling power consumption is simply to slow down the CPU clock. Since the CPU portion of the processor consumes most of the power, slowing it down has the biggest affect on power consumption.

The second approach is use one of the IDLE modes of the processor. IDLE1 stops the CPU clock entirely but leaves everything else running. Power consumption in this mode is on the order of 6 mA at 100 MHz. The CPU can be restarted by any interrupt (internal or external). In IDLE2 the system clock is stopped and this reduces consumption to 2 mA. In IDLE3, all system functions are stopped and consumption is reduced to around 2 ua. In all cases all state is retained. In IDLE2 and IDLE3, an external interrupt is required to restart the CPU. In such cases an external, low power timer would be required.

Thus with no external hardware, power consumption could be reduced to at least 6 mA and perhaps less. With a simple external timer, one could get down to microamps.

The bottom line is that the vast CPU power of the 5402 allows all lower level MAC functions to be performed in software. Furthermore it has sufficient power and memory to handle additional "higher level" functions such as packet retransmission, fragmentation, and reassembly that can also be done in a cell controller.

The system **10** of the present invention is compatible with IEEE Standard 820.11 and accordingly will operate with any mobile units **20**, including existing units, which are compatible with the same standard. However, the improvements applied to the RF ports **18**, reducing the complexity and cost of these units can also be applied to the mobile units **20**, which have sufficient main processor capacity to handle the mobile unit functions corresponding to the higher order MAC functions.

Referring to FIG. **2** there is shown a block diagram for a mobile unit **20** having a mobile unit computer **22** and a WLAN adapter **24** connected thereto to provide wireless communications to the system **10** of FIG. **1**. In the mobile unit **20** of FIG. **2**, the lower level MAC functions are performed in WLAN adapter **24**, which also includes RF module **28** and antenna **29**. The configuration of WLAN adapter **24** may be similar to existing adaptors, but preferably adapter **24** is simplified to perform only the lower level MAC functions of the IEEE 802.11 protocol and allow special software **34** in host computer **22** to perform the higher level MAC functions, such as association and roaming. In a preferred arrangement the MAC functions of adapter **24** are performed in a digital signal processor **26**, as described below, which may be the same type DSP described with respect to RF port **50**.

This section addresses how the 5402 DSP could be used as a MAC engine in Mobile Unit configurations. There are two considerations in building MU WLAN solutions. The first is the location of those MAC functions, while the second is the physical interface to the host.

The location of the upper level MAC functions may vary considerably. Some possibilities are:

- All functions on MAC engine DSP processor **26**
- All functions on host processor **22**
- Roaming/association on host processor **22**, rest on MAC engine **26**
- Roaming/association/retransmission on host **22**, rest on MAC engine **26**. The choice of the location of the higher level MAC functions has a major impact on the cost of MU WLAN adapter. If one is willing to place at least some of the higher level functions on a host processor **22**, then one could get by with just the 5402 on the WLAN adapter. Possible functions to place on the host would be roaming and association control. Higher level functions such as retransmission and fragmentation/reassembly could be left on the 5402. This split would permit significant savings, since another processor/memory subsystem would not be needed on the WLAN adapter. There are two reasons for not placing all of the MAC functions on the 5402. The first is memory space on the 5402 is only 32KB of SRAM for both code and data. In some MAC implementations such as frequency hop, the code space alone exceeds 32 KB. The second reason is that the software on the 5402 is oriented toward meeting hard, real-time tasks such as CRC and WEP processing. Trying to add software intensive tasks would only complicate the process.

If another processor was required, such as an ARM or perhaps a second 5000 Series processor, the upper level functions could be added to it.

Alternatively one could place all the MAC functions on a faster and/or bigger version of the 5402 processor. Such a processor would likely have a higher clock rate (current members of the 5000 Series can be clocked as high as 160 MIPS) and more memory (say 64 KB instead of 32KB).

Both the second processor as well as a faster/bigger 5402 would consume additional power as well as adding cost.

This section will describe one approach of how a MU WLAN adapter can be arranged for various hardware host interfaces using the 5402. It assumes that enough of the upper level MAC functions have been offloaded to a host processor so that only the 5402 is required on the PLAN adapter. A second processor could be added to any of the solutions outlined below.

In all of the following solutions, it is assumed that the runtime code for the 5402 is loaded from an external source (such as computer **22**) via the host interface **32**. This eliminates the need for flash memory on the adapter card, saving several dollars in the process. It should be pointed out that the 5402 comes with 8KB of mask programmable ROM and a bootloader program (required for the USB and Ethernet host interfaces) would be placed in it. The bootloader would be smart enough to download the runtime code instructions over whatever serial interface was available.

The simplest interface of all would be for a host to use the Host Port on the 5402. This port operates as a dual port interface into the memory within the 5402. It would not be a standard interface but would be quite suitable for dedicated systems. Using it, computer **22** can read/write memory on a random or sequential basis. It is an 8 bit interface and can operate as fast as 160 Mbit/sec. When operated in random access mode, the computer **22** generates a 16 bit address using two writes to the port and then performs either a read or write operation. Such a mode allows a host to set up command blocks and the like within the memory of the 5402. Sequential mode allows a host to transfer data in and out of the 5402 memory very quickly (160 Mbit/sec). This would be used for transferring data.

If this approach was used, the only digital component on the WLAN adapter would be the 5402.

In the system of FIG. **1**, the cell controller **14** is a board level personal computer coupled to the switching hub **12** preferably by 10 M bit and 100 Mb Ethernet ports. For smaller systems a 350 MHz Pentium computer with 16 MB RAM may be used. For larger systems having many RF ports a 500 MHz Pentium with 64 MB RAM is appropriate. Communications to and from the wired network are preferably carried out at 100 MHz. Communications to and from RF ports may be carried out at 10 MHz. A second cell controller may be supplied for larger systems and/or to provide backup in the event one cell controller fails. Reliability can be enhanced by providing dual fans and dual power supplies. A flash disk memory may be used for reliability. Alternately, the cell controller **14** may be built into the switching hub **12** or into a host processor.

The operating system for the cell controller **14** may be a real time operating system, such as VRTX or QNX, which provides multitasking, a full network stack and utilities. Web based management utilities, which are client side java based, are provided for maintaining the configuration of the cell controller **14**, the RF ports **18** and status of the mobile units **20**.

The cell controller **14** includes applications to provide mobile unit association management, roaming and packet

buffer management. These applications are similar to those performed by current access points in the Spectrum 24 system. The cell controller **14** may also provide QoS support, user authorization and configuration management. Placing these functions on a personal computer cell controller facilitates system management and program updates using available programming tools. Further, modifications to authorization or management functions need only be installed into the cell controller **14**, and no modification to the software of the RF ports **18** is required.

The cell controllers **14** handle routing of all messages to or from the mobile unit. The cell controller buffers message packets received from the wired network and determines the appropriate RF port **18** with which the addressed mobile unit **20** is associated and sends the packet to the RF port **18**. The cell controller **14** can additionally perform WEP encryption/decryption and the CAC associated therewith.

The cell controller **14** may also the additional function of maintaining and downloading firmware to the RF ports **18**. Upon power up the RF ports **18** use a bootloader routine stored in ROM to send a download request to cell controller **14**. The cell controller then downloads firmware to the RF port **18**, including configuration information such as channel assignment, ESS and BSS identification. The cell controller **14** and RF ports **18** additionally share a common TSF clock.

The mobile unit computer **22** of mobile unit **20** is provided with similar software to perform the higher level MAC functions as outlined above. Advantageously, the software **34** can be programmed using the same operating system as provided for the computer, and thereby provide a user interface, such as Windows, which is familiar to the user. The mobile unit software **34** provides the MAC functions of header building, roaming and association. The mobile unit computer **22** may also download firmware to the processor in the WLAN adapter **24**.

As evident from the forgoing description, the hardware for RF port **18** and WLAN adapter **24** of mobile unit **20** can be substantially similar, with the possible exception of the interface to an Ethernet network or to a mobile unit host. Further, the logical cell controller function and the higher order MAC functions performed by the mobile unit host processor can be performed on any computer system.

Using the RF port **18** of the present invention coupled to a computer system, it is possible to provide either a mobile unit or a wireless network according to the software provided. Since the software for RF port **18** may be downloaded from a host system a simple combination of a computer and one or more RF ports can function as either a WLAN mobile unit as a WLAN host or both, by providing function selectable firmware to the processor in the RF port.

In the arrangement shown in FIG. **5**, a personal computer **70** is provided with software **72** and connected to one or more RF ports **50**A, **50**B to provide a complete host system for wireless data communications. This arrangement could be used, for example, in a small business wherein office equipment is connected to server **70** by a wired network for conventional LAN operation and one or more RF ports **50** are also connected to server **70** on the LAN system to provide data communications between the server **70** and mobile units. The server can perform the higher order MAC functions and download firmware instructions to the RF ports. Alternatively, the firmware instructions can be installed on PROM memory in the RF ports.

FIG. **6** shows an arrangement for providing wireless access to the Internet using the RF port **50** of the present invention. Internet access over communications line **80** to modem **82** may be provided by cable, DSL or fiber optical transmission. RF port **50** may be provided with MAC firmware on PROM or may be configured with a bootloader program to download firmware from an ISP server. When installed in a home or office, mobile units **20** can associate with RF port **50** to initiate Internet access. The ISP server may perform the higher level MAC function, or they may be provided in RF port **50**.

The mobile units **20** may be the personal computers **22** in a home or office with a WLAN adapter **24** as shown in FIG. **2**.

FIG. **7** illustrates an example of communications formats that might be used in the various system embodiments of the present invention. The FIG. **7** example assumes that the configuration includes a host **90** connected to a dedicated cell controller **14**, which is likewise connected to RF port **18**. It should be clearly understood that the logical cell controller functions may be performed in host **90**, particularly in a simple system.

In the FIG. **7** example host **90** sends message "A" having 100 data bytes via an Ethernet packet **100** to cell controller **14**. Packet **100** has a destination address of the Mobile unit (M1), a source address of the host (H) and includes data (A). Cell controller **14** formats the data in 802.11 format with the destination corresponding to mobile unit (MU1) **20**. The cell encapsulates this 802.11 packet with data A into an Ethernet packet **104** addressed to RF port **1** (RF1) from the cell controller (cell controller).

RF port **18** receives the Ethernet packet **104** from cell controller **14** and generates and sends an RF packet **112** in 802.11 format to mobile unit **20**, including data A. It should be understood that 802.11 header generation can be provided at either the cell controller **14** or the RF port **18**, but packet **104** must include mobile unit identification data either as an 802.11 header or otherwise to enable RF port **18** to generate the header. RF port **18** additionally performs the CRC computation and adds the result to the 802.11 packet **112**.

A second message "B" having 1500 bytes of data is also shown as originating as Ethernet packet **102** from host **90** to cell controller **14**. Cell controller fragments data message B into three fragments B1, B2 and B3 to accommodate the 500 byte data limit of 802.11 packets. These three fragments are sent as Ethernet packets **106**, **108**, **110** to RF port **18**, which transmits RF signal packets **114**, **116**, **118** to mobile unit **20**.

Reverse communication is similar. Message C has 100 bytes and is sent by mobile unit **20** to RF port **18** as 802.11 RF signal packet **200**. RF port **18** encapsulates this message into Ethernet packet **208** and sends it to cell controller **14**, which extracts the destination information and data to provide Ethernet message **216** to the host **90**. A larger message D is sent as message fragments **202**, **204**, **206** to RF ports **18**, relayed as Ethernet packets **210**, **212**, **214** to cell controller **14** and sent as a reassembled Ethernet packet **218** to host **90**.

Referring now to FIG. **8**, shown is an application of the central controller/RF port model that may be used to set multiple overlapping ESS LANs for use in the same or overlapping physical space. Shown in FIG. **8** is a central controller **260** which is associated with two RF ports, RF port **1 250** and RF port **2 270**. The central controller **260** may be associated with more than two RF ports, but two are shown for illustration purposes. Each RF port **250**, **270** provides coverage for a wireless LAN in the physical areas **240**, **310**.

FIG. **8** further illustrates the concept of providing multiple ESS identifications through the same RF port and cell controller such that each ESS identification is associated with a separate virtual wireless local area network having its own policies and security. Thus, RF port **1 250** may be configured so as to support separate BSS networks **1**A **230**, **1**B **220** and **1**C **210**, all of which occupy the same physical space **240**. The RF port may support more than three BSS networks, but three are shown for illustration purposes. Similarly, RF port **2 270** may be configured so as to support

BSS networks **2A 300**, **2B 290** and **2C 280**, all of which occupy the same physical space **310**. Using the configuration as shown in FIG. **8**, multiple ESS LANs may be coordinated by the central controller **260** in the physical space **240** and **310**. ESS A personnel, such as airport employees, may have access to the public level and also have access to the airport operational network. The security-based network would be available for select airport personnel such as management and security officers.

The cell controller performs the function of determining which ESS network a mobile unit communicating with an RF port associated with the cell controller is operating on, and thereby controls the direction of communication from the cell controller to the network. The cell controller can verify the multiple levels of security provided in connection with the access by the mobile unit devices, and in addition can prioritize communications so that higher priority communications such as security communications are given greater access to the system during higher traffic conditions. For example, in the three-tier embodiment discussed above, the security network could have a feature to disallow all other network access in an emergency situation.

A similar multi-virtual LAN network may be also useful in a health care facility wherein different networks are used for security, medical care, personal and public information.

The architecture described herein offers advantages in several discrete areas of wireless network management.

Bandwidth Management

An aspect of functionality that can be realized in connection with the configuration described herein is to modify the bandwidth of communications in accordance with the type of device with which the communication is associated. For example, where a data set comprises an image, for example retrieved from the Internet, the resolution of the image can be modified in the cell controller to accommodate the resolution capacity of a portable device. Therefore, rather than provide a highly detailed image of the type that can be displayed on a personal computer, an image-bearing message can be reduced in resolution in the cell controller to a lower resolution, compatible with a portable device, such as a personal digital assistant. By therefore reducing the resolution of the image being sent, the bandwidth and data capacity necessary to send the image can be significantly reduced.

Another functionality available with the configuration described herein is to control the individual RF ports according to the traffic experienced by the system. For example, the cell controller can assigned an RF port experiencing a high volume of communication to a different channel, such as a reserve channel on which no other RF ports are operating. This will minimize interference in communications conducted with a particular RF port that is experiencing high volume. In this manner the RF port may be the only RF port operating on the particular, reserve channel. The cell controller has real time information available to it in order to make the changes in the RF port configuration to accommodate changing load conditions.

A wireless system may also contain RF ports sending and receiving overlapping 2.4 GHz, Bluetooth, and 5 GHz signals. These signals will have differing frequencies, power levels, and data rates. Because the cell controller will monitor all features of the frequencies generated by the RF ports and will know the locations of the RF ports, the cell controller will have the ability to optimize the frequency, power level and data rates in the physical space for the best possible performance.

The cell controller provides a central location for interfacing the WLAN with WAN features that may be accessed by users. For example, the cell controller can coordinate the processing necessary to enable voice over IP (VoIP), i.e. compression or user allocations. Compression is particularly enhanced using a cell controller because the cell controller can maintain the necessary historical dictionaries needed for efficient compression algorithms in one location that applies to all RF ports. The cell controller can also proxy to access a SIM database for WAN users in advance of actually needing this data to perform operations.

The cell controller allows additional functionality to the WLAN at all levels while maintaining the compatibility in the MAC level necessary for IEEE 802.11 systems. One such example would network management features that are not present in the 802.11 protocol but would be useful to operate at the cell controller/RF port level. An embodiment of this is to monitor the software versions present in the MUs in a WLAN and send out updated versions when each MU "checks in" with the cell controller. Ultimately this allows the costs of APs/RF ports to remain relatively inexpensive.

Other aspects of routing traffic through the cell controller is the ability to detect interference and noise and the ability to control the transmit power of particular RF ports. For example, the cell controller can command the RF port to provide the signal level they are receiving when there is no communication (background noise or interference) to the cell controller. This can be used to provide an analysis of the system operation or to provide the detection of background interference and its location.

Security

Another available function of this architecture is control of association, since all association is handled in a cell controller. Accordingly, where a "public access only" device attempts to associate with the system in a secure area such as, for example, an airport control tower, where a member of the public should not be, the fact of this association attempt can be noted in the cell controller and automatically give notice to security personnel. The cell controller can additionally deny or permit access to a mobile unit attempting to associate with an RF port according to traffic at the RF port as observed at the cell controller. The cell controller thereby has a measure of control over roaming and can command a mobile unit as to which RF port to become associated with. Indeed, under many WLAN architectures, APs do not coordinate with each other to determine if they are being probed in such a way that an attempt to break security may be occurring. In contrast, a cell controller can monitor all such probing to determine if an attack may be taking place. Logs of such probing may be kept. In addition, authentication protocols may be centralized in the cell controller instead of on a central server, creating greater efficiency.

Another important aspect of control of association and roaming in the cell controller is the fact that the cell controller can perform a "soft-roaming" function. Soft-roaming takes place when the cell controller changes ownership of the BSS identification between RF units. In essence the cell controller has the ability to tell a mobile unit which RF port it will communicate through. In connection with doing so it is possible for one RF port to monitor traffic to another RF port and thereby advise the cell controller that it has the capability of receiving signals from that particular mobile unit. The cell controller has the ability to control the access of the mobile units to RF ports according to traffic as observed in the cell controller. One aspect of the system is that the intelligence in the cell controller interacts with the intelligence in the mobile unit to control association. The RF port has no part in this and accordingly there is a greater ability to centrally managed the flow of traffic through the RF port. Another aspect is to provide an arrangement in the cell controller wherein only one RF port can perform secure data communication. When a mobile unit desires a secure link, the cell controller can switch the mobile unit to a particular RF port for secure communications. In essence the

unit is capable of providing a virtual RF port. The switching of the BSS identification between RF ports takes place in the cell controller and the mobile unit has no idea that it has been given the bait and switch. Another aspect of the centralized management is security, in that if a mobile unit which does not have access authorization attempts a number of times to gain access to the system, the security program in the cell controller can provide an alert and in essence lock out further attempts by that mobile unit.

Location Tracking

In the architecture described herein, because RF ports are cheaper than typical APs, there may be more RF ports in a given area than APs. This proliferation of RF ports will allow location tracking to take place. Moreover, one RF port has the ability to "snoop" and listen in to the traffic between another RF port and a mobile unit. The cell controller can take all this data in and use time stamping based on the arrival of data. Such information can be passed through the Ethernet to a processor that can determine location.

Diagnostic Capability

An important capability which the cell controller can also implement is the diagnostic capability. As an initial calibration when a system is first brought into operation the cell controller can cause the RF ports to go through a sequence in which the RF ports communicate to each other. In this way the signal level of each RF port, as observed at one or more other RF ports, can be monitored and the radio location of the RF ports can be mapped, for example, to create alternative RF ports to which traffic can be switched in the event of excess traffic on any particular RF port. Accordingly using RF signals the cell controller can dynamically discover the RF locations and signal characteristics between RF ports. Each RF port in this case would provide the cell controller with an indication of the strength of the signals received. The cell controller can also record the background noise level. Following the initial calibration of the system the cell controller can undertake periodic diagnostics, wherein signals are sent from one RF port to another and the signal level is relayed to the cell controller to determine whether if the transmitters and receivers are operating properly. In this respect, the signals received can be compared to the base line signal levels which have been recorded at the cell controller as a calibration level. Changes in background noise can also be determined and this can be used to detect a problem with a receiver in the system.

While there has been described what is believed to be claimed in the above-identified application those skilled in the art will recognize that other and further modifications may be made without departing from the scope of the invention and it is intended to claim all such changes and modifications as fall within the true scope of the invention.

I claim:

1. A system for providing wireless data communications between mobile units and a wired network operating according to a wireless data communications standard protocol having high level MAC functions and low level MAC functions, comprising:

a plurality of RF ports configured to perform the low level MAC functions of the wireless data communications standard protocol, the RF ports having at least one data interface and a security status, said RF ports being arranged to receive formatted data signals at said data interface and transmit corresponding RF data signals and arranged to receive RF data signals and provide corresponding formatted data signals; and

at least one cell controller separately housed from said plurality of RF ports and configured to perform the high level MAC functions of the wireless data communications standard protocol, the at least one controller arranged to receive data signals from said wired network and to provide formatted data signals corresponding thereto to said data interface of said RF ports and to receive formatted data signals from said RF ports and to provide data signals corresponding thereto to said wired network, said cell controller controlling association of mobile units with one of said RF ports based on the security status of the one of said RF ports, providing formatted data signals for said mobile units to an associated RF port, and receiving formatted data signals from said mobile unit from said associated RF port.

2. The system specified in claim **1** wherein the wireless data communications standard protocol is the IEEE 802.11 standard protocol.

3. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a cyclic redundancy check function.

4. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a network activity vector function.

5. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a ready to send/clear to send function.

6. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a header generation/parsing function.

7. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a collision avoidance function.

8. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include a frequency hopping function.

9. The system specified in claim **1**, wherein said low level media access control functions performed by said RF ports include an ack parsing/generating function.

10. The system specified in claim **1**, wherein said lower level media access control functions performed by said RF ports include a retransmission timeout function.

11. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a roaming function.

12. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a retransmission function.

13. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a rate control function.

14. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a host interface function.

15. The system specified in claim **1**, wherein said lower level media access control functions performed by said RF ports includes a cyclic redundancy check function, a network activity vector function, a ready to send/clear to send function, a header generation/parsing function, a collision avoidance function, a frequency hopping function, an ack parsing/generating function, and a retransmission timeout function.

16. The system specified in claim **1**, wherein said higher level media access control functions performed by said cell controller include a roaming function, a retransmission function, a rate control function, a host interface function.

* * * * *

EXHIBIT C

US006625454B1

(12) **United States Patent**
Rappaport et al.

(10) **Patent No.: US 6,625,454 B1**
(45) **Date of Patent: *Sep. 23, 2003**

(54) **METHOD AND SYSTEM FOR DESIGNING OR DEPLOYING A COMMUNICATIONS NETWORK WHICH CONSIDERS FREQUENCY DEPENDENT EFFECTS**

(75) Inventors: **Theodore Rappaport**, Salem, VA (US); **Roger Skidmore**, Blacksburg, VA (US); **Eric Reifsneider**, Blacksburg, VA (US)

(73) Assignee: **Wireless Valley Communications, Inc.**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 299 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/633,121**

(22) Filed: **Aug. 4, 2000**

(51) **Int. Cl.**[7] **H04B 17/00**

(52) **U.S. Cl.** **455/446**; 455/422; 455/423; 455/424; 455/425; 455/67.1; 703/21; 703/22

(58) **Field of Search** 455/560, 561, 455/422, 423, 424, 425, 446, 67.1; 703/2–4, 21, 22

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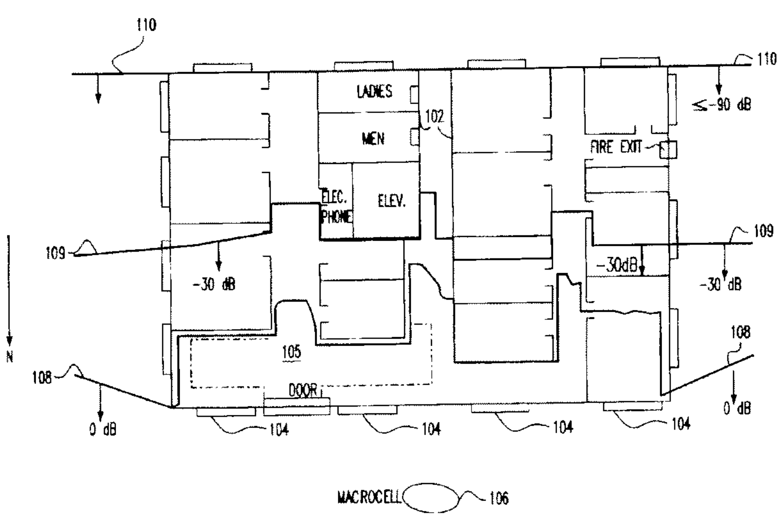
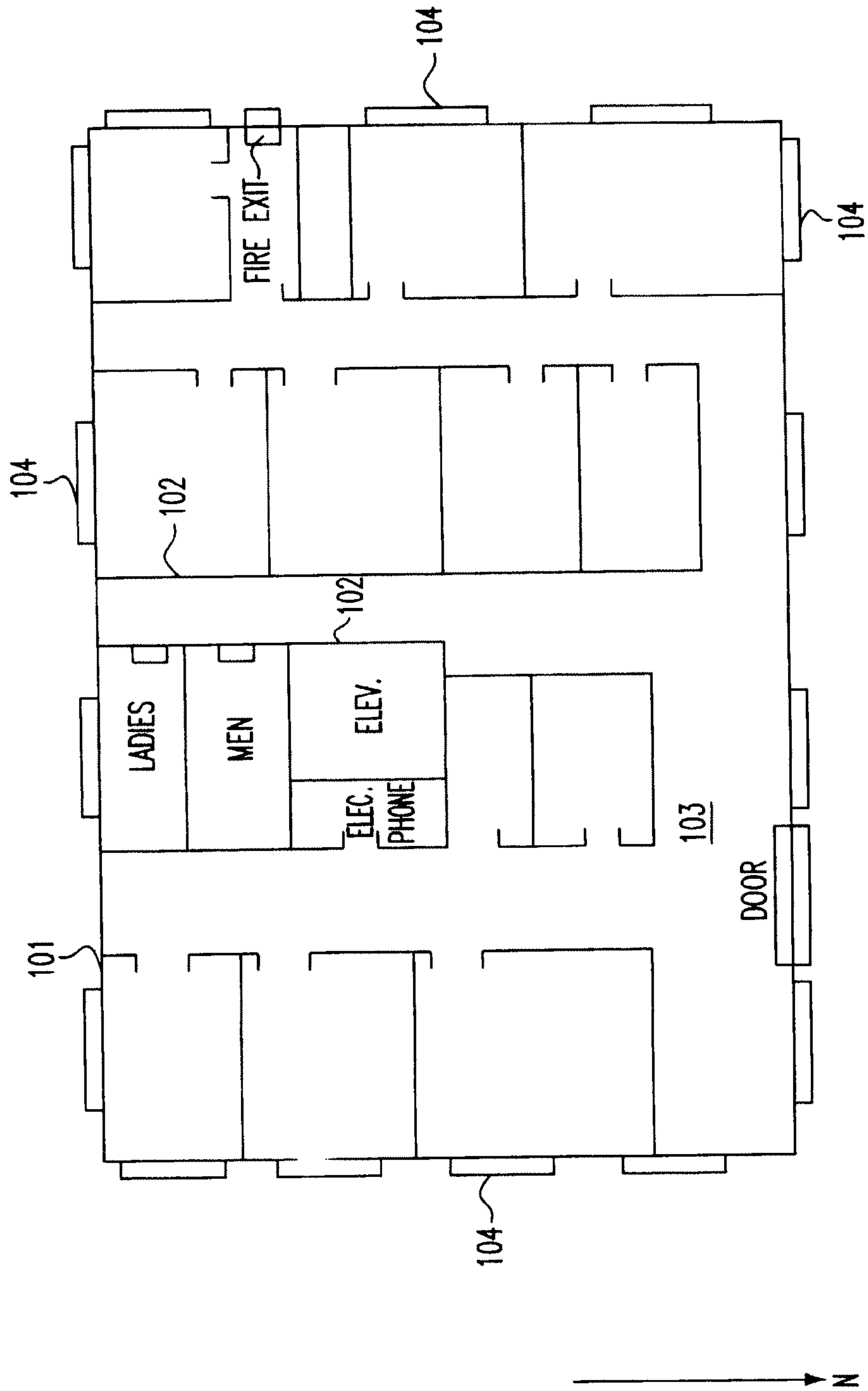
Assistant Examiner—Earl Moorman
(74) *Attorney, Agent, or Firm*—Whitham, Curtis & Christofferson, PC

(57) **ABSTRACT**

A computerized model provides a display of a physical environment in which a communications network is or will be installed. The communications network is comprised of several components, each of which are selected by the design engineer and which are represented in the display. Errors in the selection of certain selected components for the communications network are identified by their attributes or frequency characteristics as well as by their interconnection compatibility for a particular design. The effects of changes in frequency on component performance are modeled and the results are displayed to the design engineer. A bill of materials is automatically checked for faults and generated for the design system and provided to the design engineer. For ease of design, the design engineer can cluster several different preferred components into component kits, and then select these component kits for use in the design or deployment process.

14 Claims, 22 Drawing Sheets




104
104
FIRE EXIT
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102
102
LADIES
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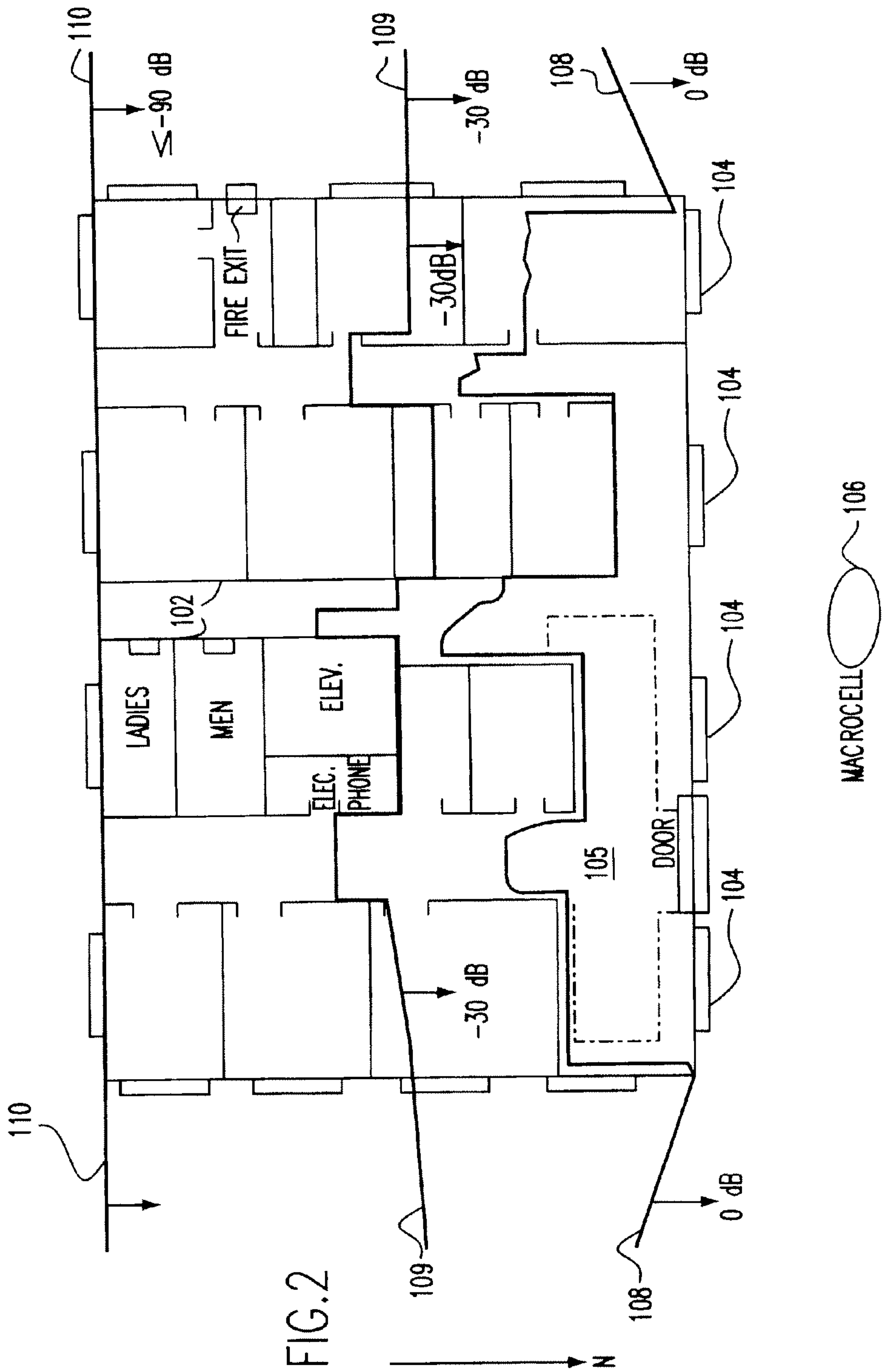
ELEV.
ELEC.
PHONE
103
DOOR
101
104
N

FIG. 1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-30 dB
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PHONE
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DOOR
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MACROCELL
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0 dB
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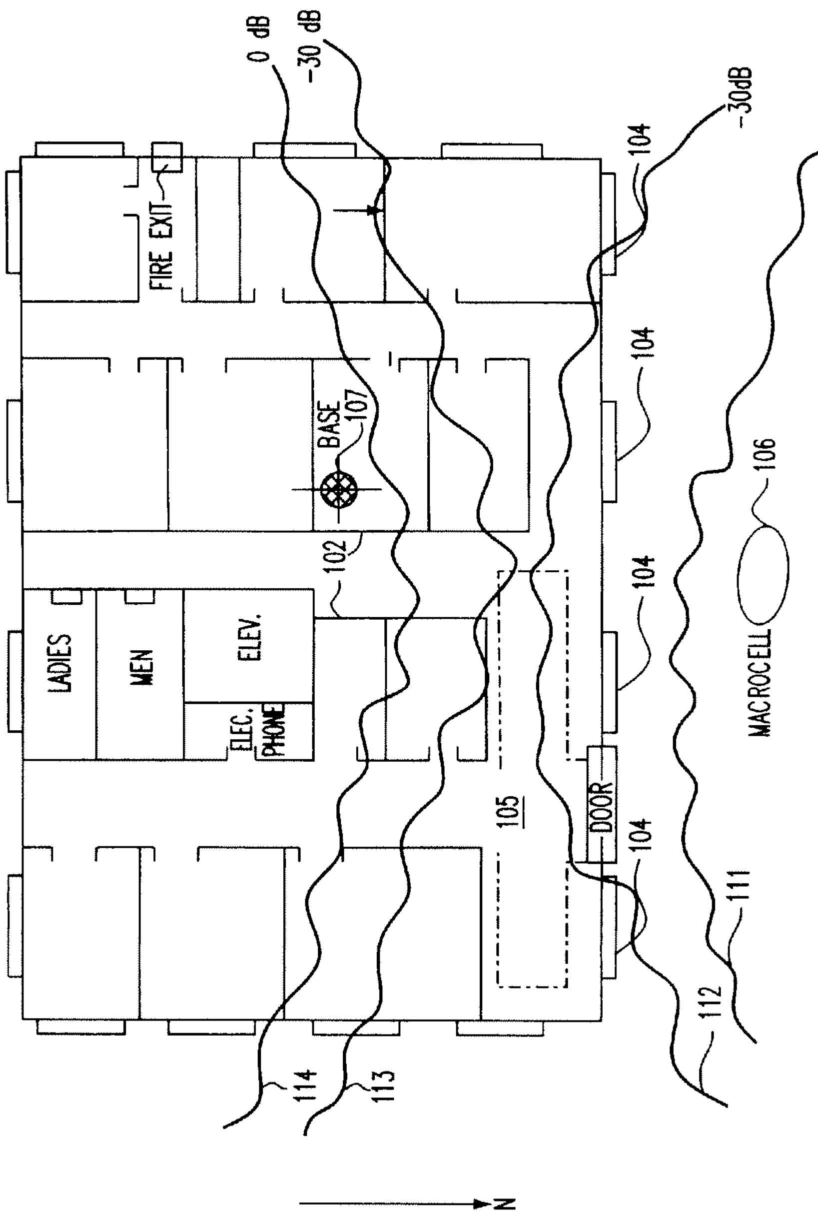
FIG. 2



0 dB
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0 dB
104
FIRE EXIT
BASE
107
102
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DOOR
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112
113
114
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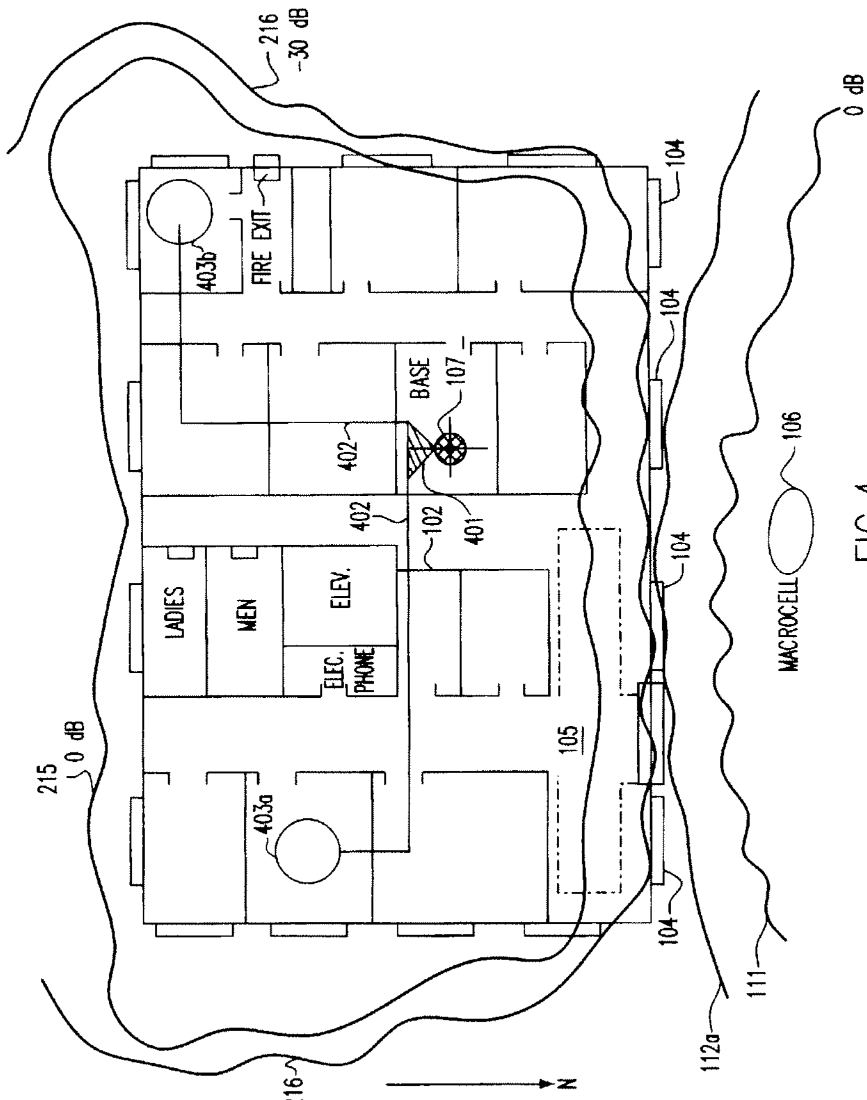
FIG. 3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102
106
MACROCELL
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ELEV.
ELEC.
PHONE
105
215
0 dB
403a
111
112a
216
N

FIG. 4

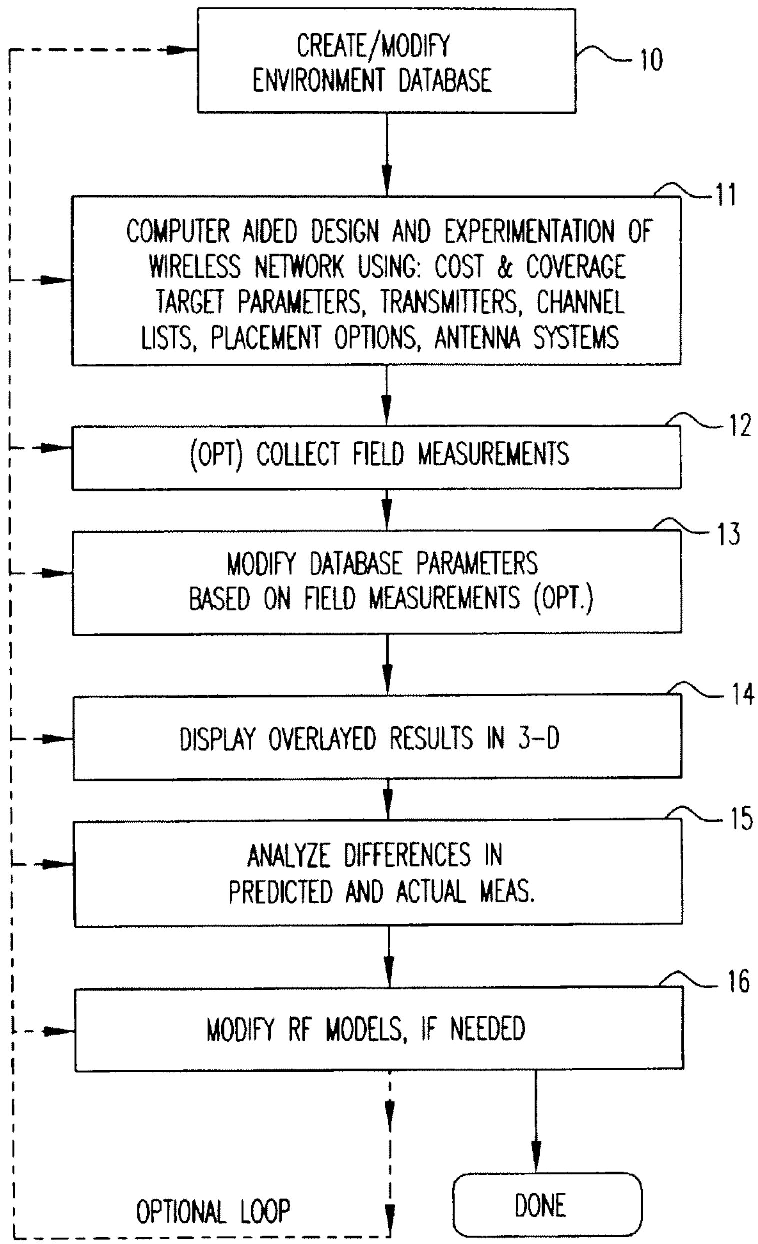

CREATE/MODIFY ENVIRONMENT DATABASE
10
COMPUTER AIDED DESIGN AND EXPERIMENTATION OF WIRELESS NETWORK USING: COST & COVERAGE TARGET PARAMETERS, TRANSMITTERS, CHANNEL LISTS, PLACEMENT OPTIONS, ANTENNA SYSTEMS
11
(OPT) COLLECT FIELD MEASUREMENTS
12
MODIFY DATABASE PARAMETERS BASED ON FIELD MEASUREMENTS (OPT.)
13
DISPLAY OVERLAYED RESULTS IN 3-D
14
ANALYZE DIFFERENCES IN PREDICTED AND ACTUAL MEAS.
15
MODIFY RF MODELS, IF NEEDED
16
OPTIONAL LOOP
DONE

FIG.5

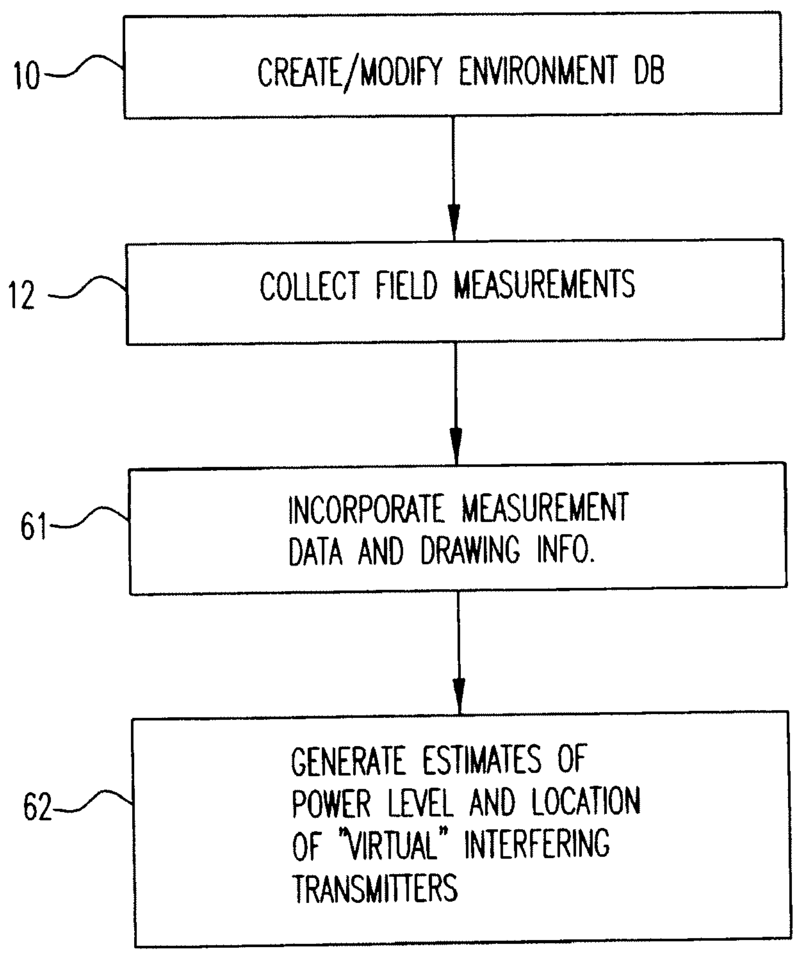

10
CREATE/MODIFY ENVIRONMENT DB
12
COLLECT FIELD MEASUREMENTS
61
INCORPORATE MEASUREMENT DATA AND DRAWING INFO.
62
GENERATE ESTIMATES OF POWER LEVEL AND LOCATION OF "VIRTUAL" INTERFERING TRANSMITTERS

FIG.6

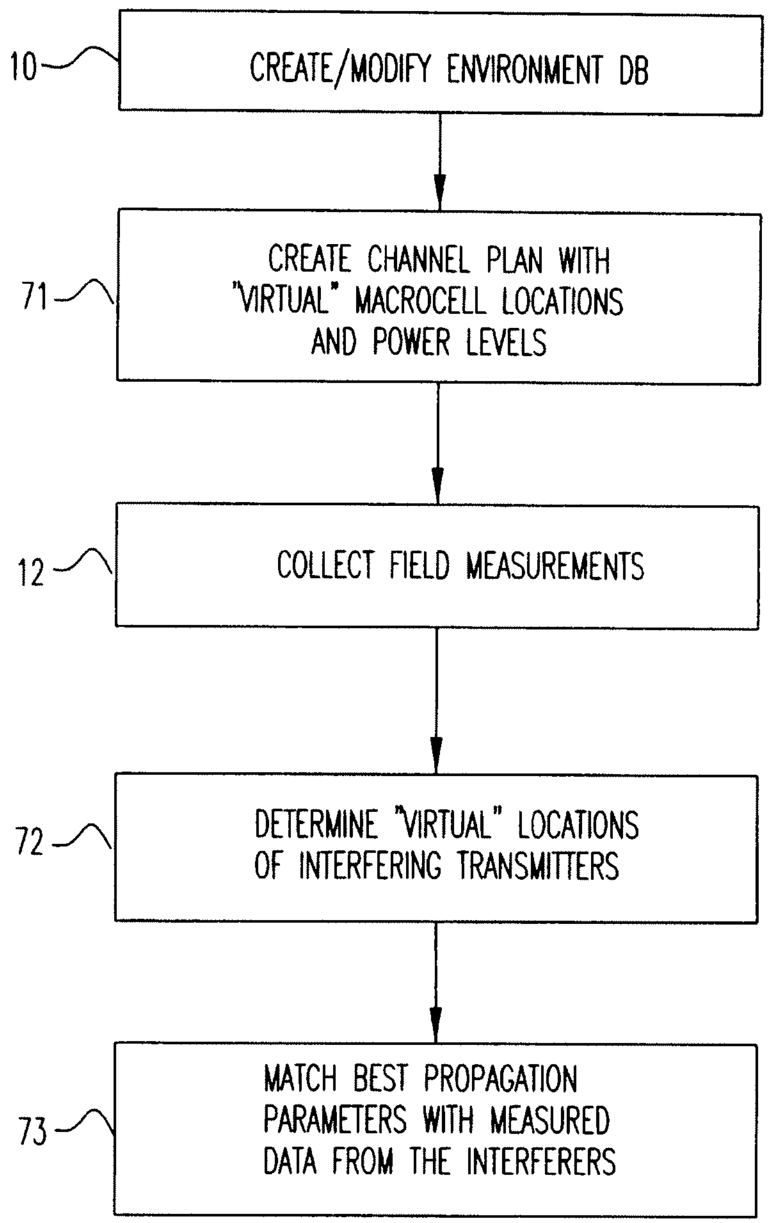

10
CREATE/MODIFY ENVIRONMENT DB
71
CREATE CHANNEL PLAN WITH "VIRTUAL" MACROCELL LOCATIONS AND POWER LEVELS
12
COLLECT FIELD MEASUREMENTS
72
DETERMINE "VIRTUAL" LOCATIONS OF INTERFERING TRANSMITTERS
73
MATCH BEST PROPAGATION PARAMETERS WITH MEASURED DATA FROM THE INTERFERERS

FIG.7

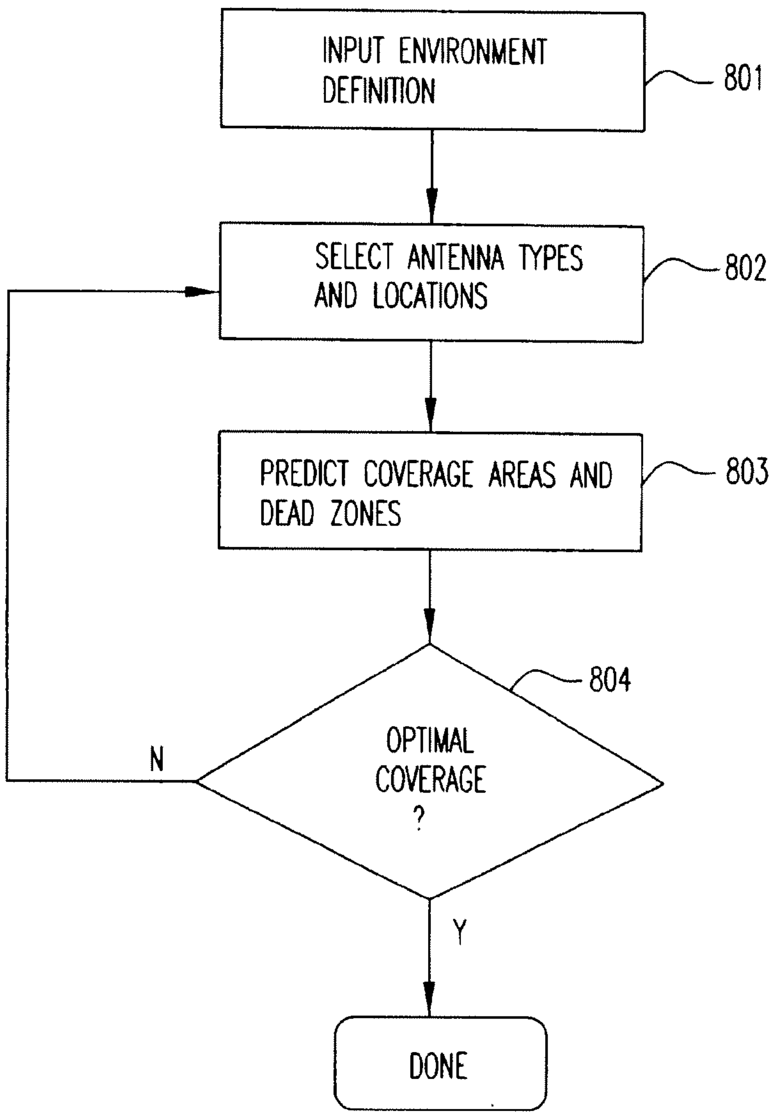
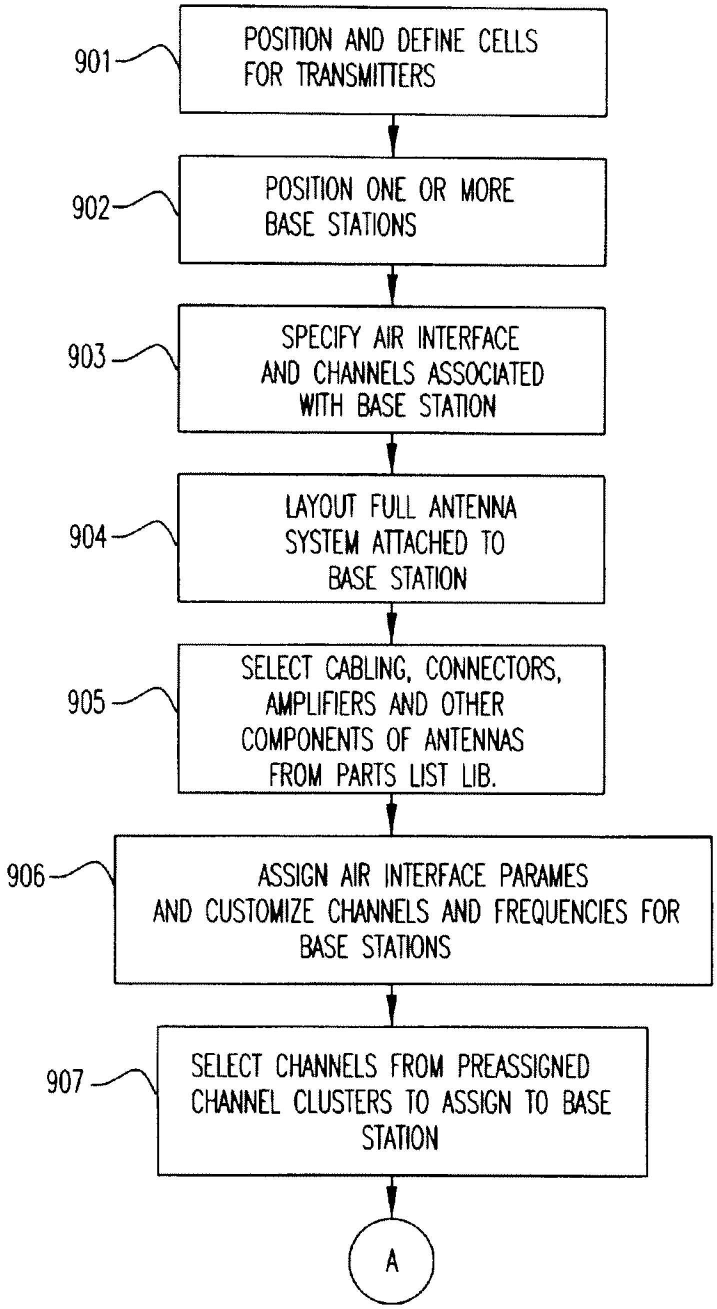

INPUT ENVIRONMENT DEFINITION
801
SELECT ANTENNA TYPES AND LOCATIONS
802
PREDICT COVERAGE AREAS AND DEAD ZONES
803
804
OPTIMAL COVERAGE ?
N
Y
DONE

FIG.8



901
POSITION AND DEFINE CELLS FOR TRANSMITTERS
902
POSITION ONE OR MORE BASE STATIONS
903
SPECIFY AIR INTERFACE AND CHANNELS ASSOCIATED WITH BASE STATION
904
LAYOUT FULL ANTENNA SYSTEM ATTACHED TO BASE STATION
905
SELECT CABLING, CONNECTORS, AMPLIFIERS AND OTHER COMPONENTS OF ANTENNAS FROM PARTS LIST LIB.
906
ASSIGN AIR INTERFACE PARAMES AND CUSTOMIZE CHANNELS AND FREQUENCIES FOR BASE STATIONS
907
SELECT CHANNELS FROM PREASSIGNED CHANNEL CLUSTERS TO ASSIGN TO BASE STATION
A

FIG.9A

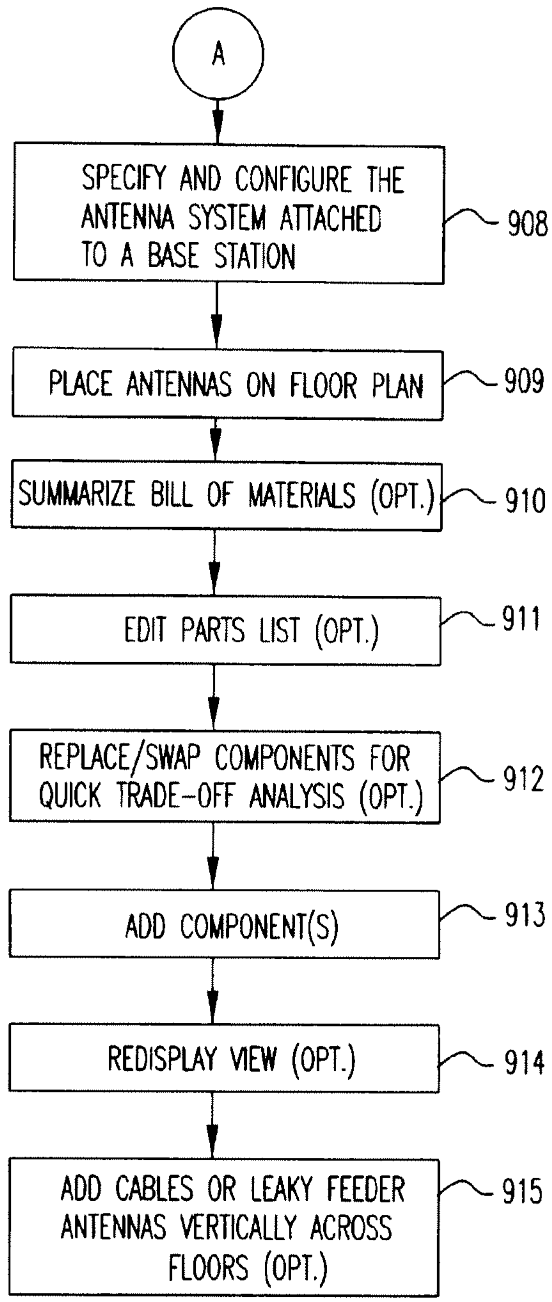

A
SPECIFY AND CONFIGURE THE ANTENNA SYSTEM ATTACHED TO A BASE STATION
908
PLACE ANTENNAS ON FLOOR PLAN
909
SUMMARIZE BILL OF MATERIALS (OPT.)
910
EDIT PARTS LIST (OPT.)
911
REPLACE/SWAP COMPONENTS FOR QUICK TRADE-OFF ANALYSIS (OPT.)
912
ADD COMPONENT(S)
913
REDISPLAY VIEW (OPT.)
914
ADD CABLES OR LEAKY FEEDER ANTENNAS VERTICALLY ACROSS FLOORS (OPT.)
915

FIG.9B

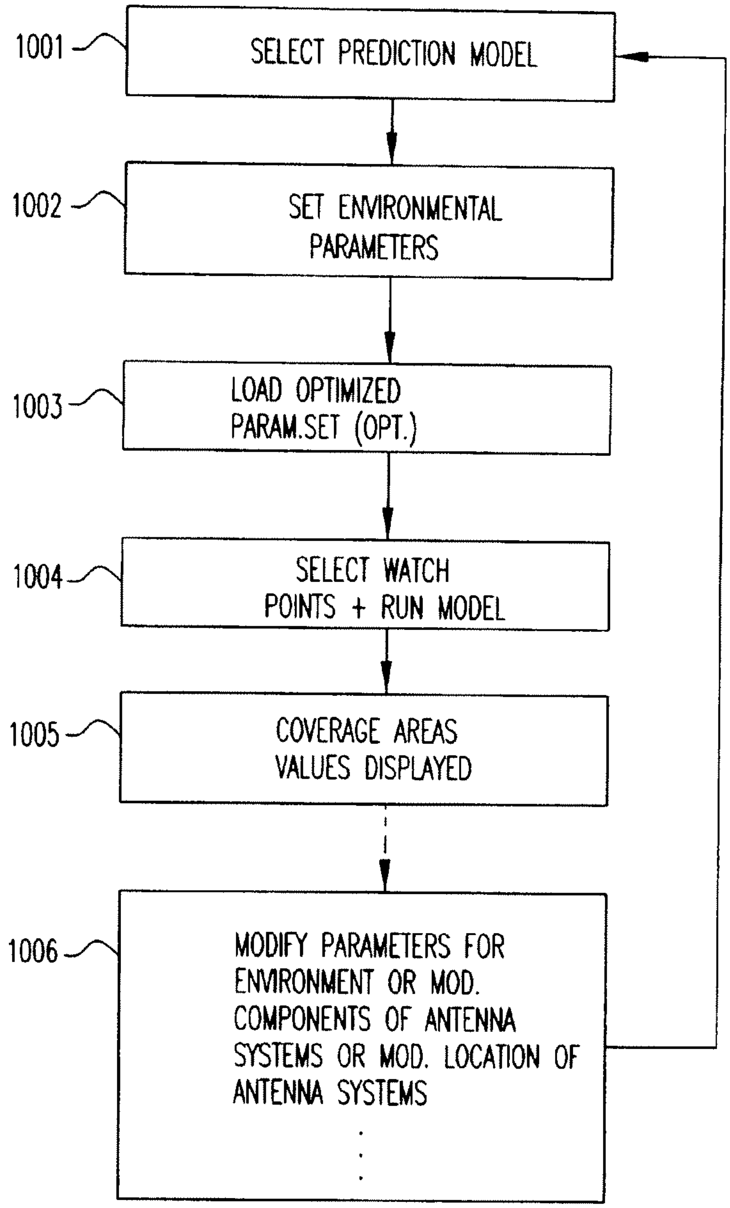

1001
SELECT PREDICTION MODEL
1002
SET ENVIRONMENTAL PARAMETERS
1003
LOAD OPTIMIZED PARAM.SET (OPT.)
1004
SELECT WATCH POINTS + RUN MODEL
1005
COVERAGE AREAS VALUES DISPLAYED
1006
MODIFY PARAMETERS FOR ENVIRONMENT OR MOD. COMPONENTS OF ANTENNA SYSTEMS OR MOD. LOCATION OF ANTENNA SYSTEMS
⋮

FIG.10

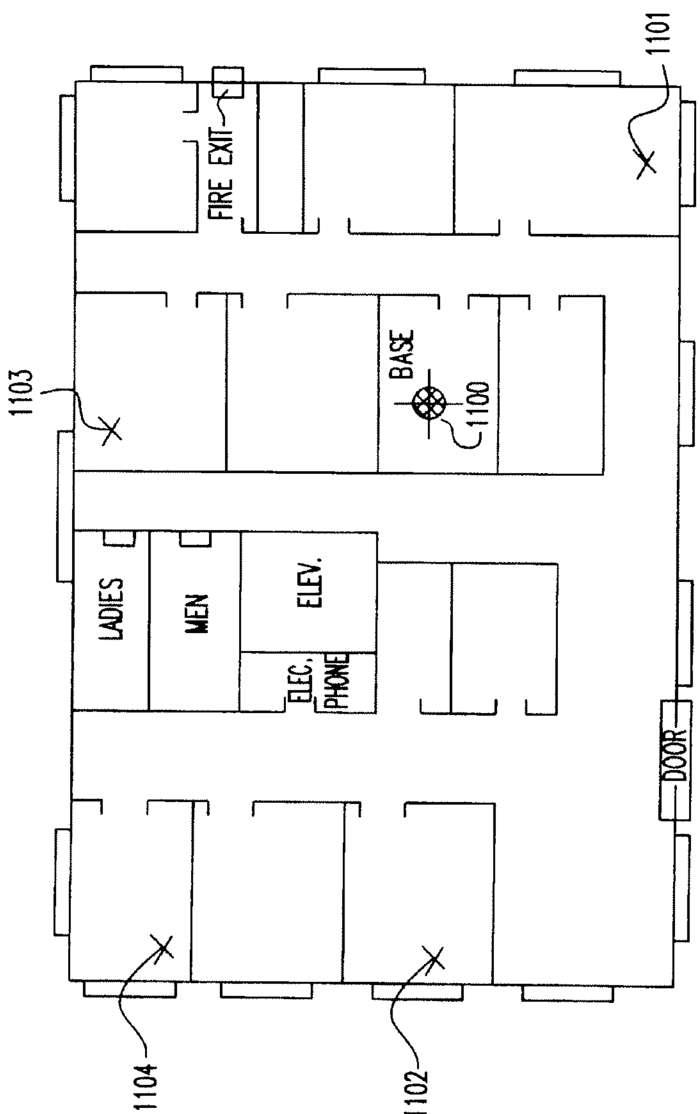

1101
FIRE EXIT
1103
BASE
1100
LADIES
MEN
ELEV.
ELEC.
PHONE
DOOR
1104
1102

FIG. 11

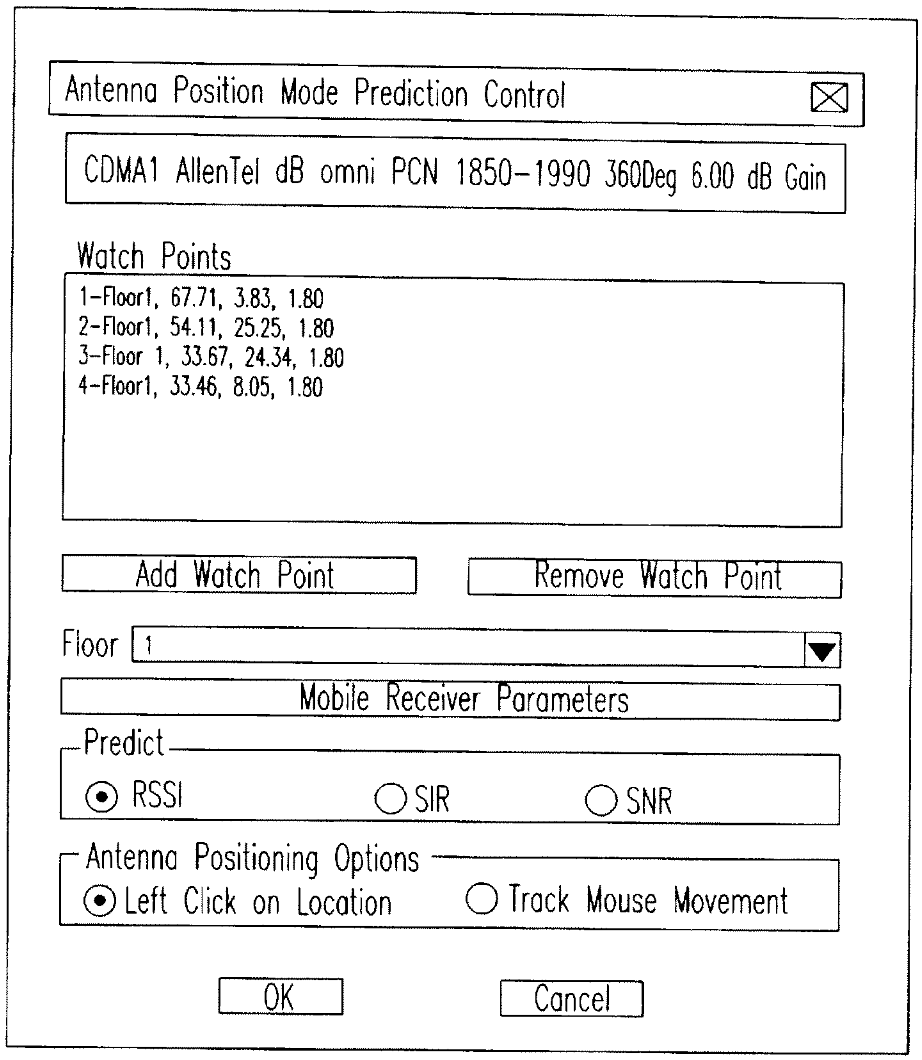

Antenna Position Mode Prediction Control
CDMA1 AllenTel dB omni PCN 1850-1990 360Deg 6.00 dB Gain
Watch Points
1-Floor1, 67.71, 3.83, 1.80
2-Floor1, 54.11, 25.25, 1.80
3-Floor 1, 33.67, 24.34, 1.80
4-Floor1, 33.46, 8.05, 1.80
Add Watch Point
Remove Watch Point
Floor
1
Mobile Receiver Parameters
Predict
RSSI
SIR
SNR
Antenna Positioning Options
Left Click on Location
Track Mouse Movement
OK
Cancel

FIG. 12

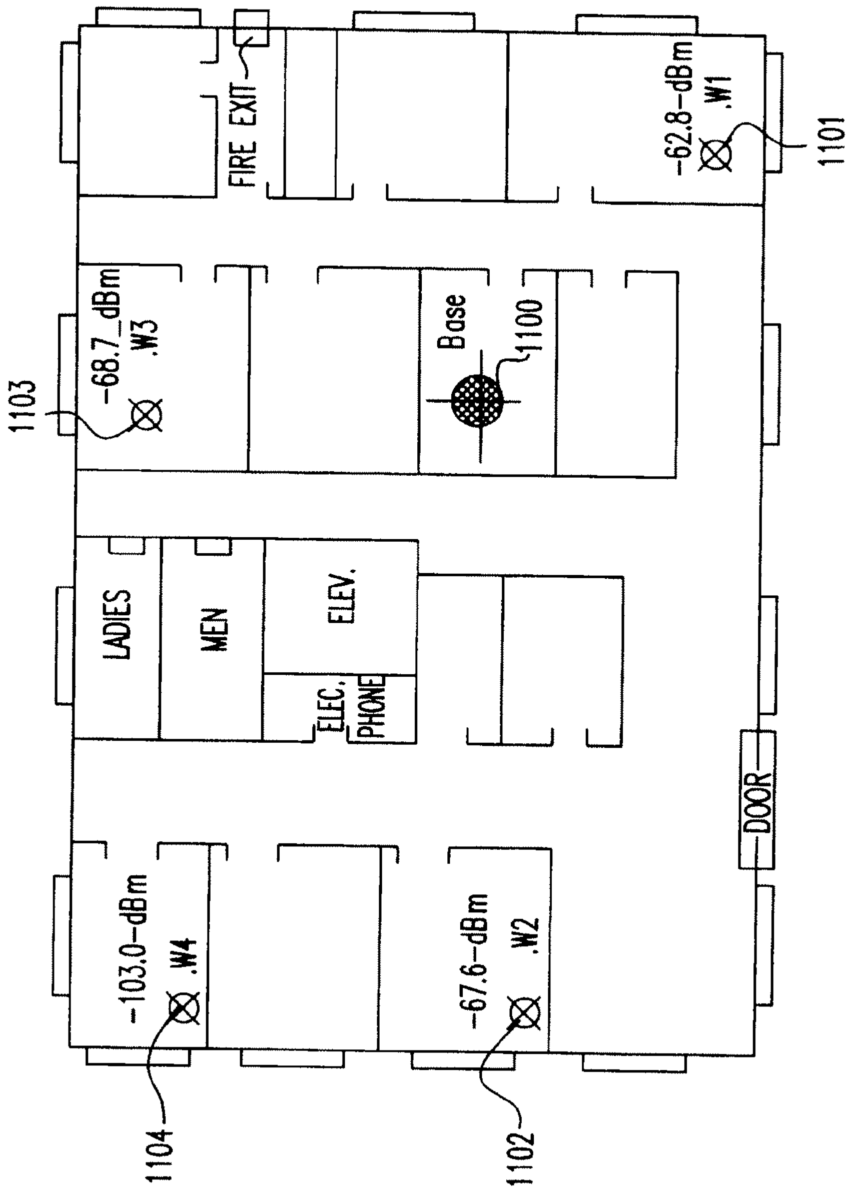

FIRE EXIT
-62.8-dBm
.W1
1101
-68.7_dBm
.W3
1103
Base
1100
LADIES
MEN
ELEV.
ELEC.
PHONE
DOOR
-103.0-dBm
.W4
1104
-67.6-dBm
.W2
1102

FIG. 13

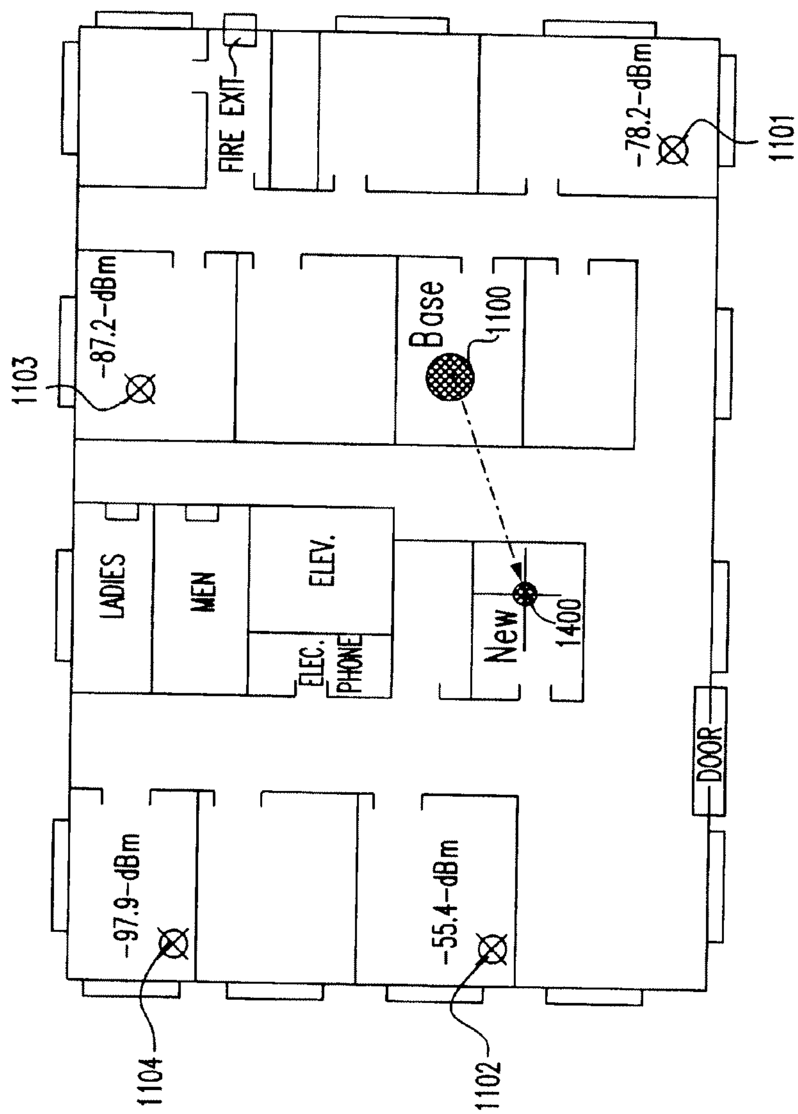

FIRE EXIT
-78.2-dBm
1101
-87.2-dBm
1103
Base
1100
LADIES
MEN
ELEV.
ELEC.
PHONE
New
1400
DOOR
-97.9-dBm
-55.4-dBm
1104
1102

FIG.14

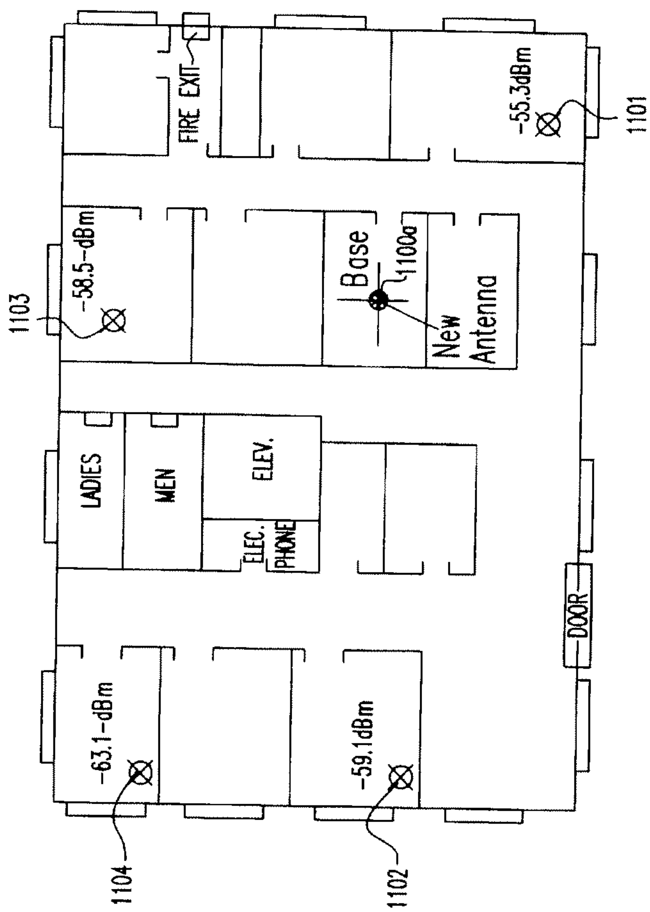

FIRE EXIT
-55.3dBm
1101
-58.5-dBm
1103
Base
1100a
New Antenna
LADIES
MEN
ELEV.
ELEC.
PHONE
DOOR
-63.1-dBm
-59.1dBm
1104
1102

FIG. 15

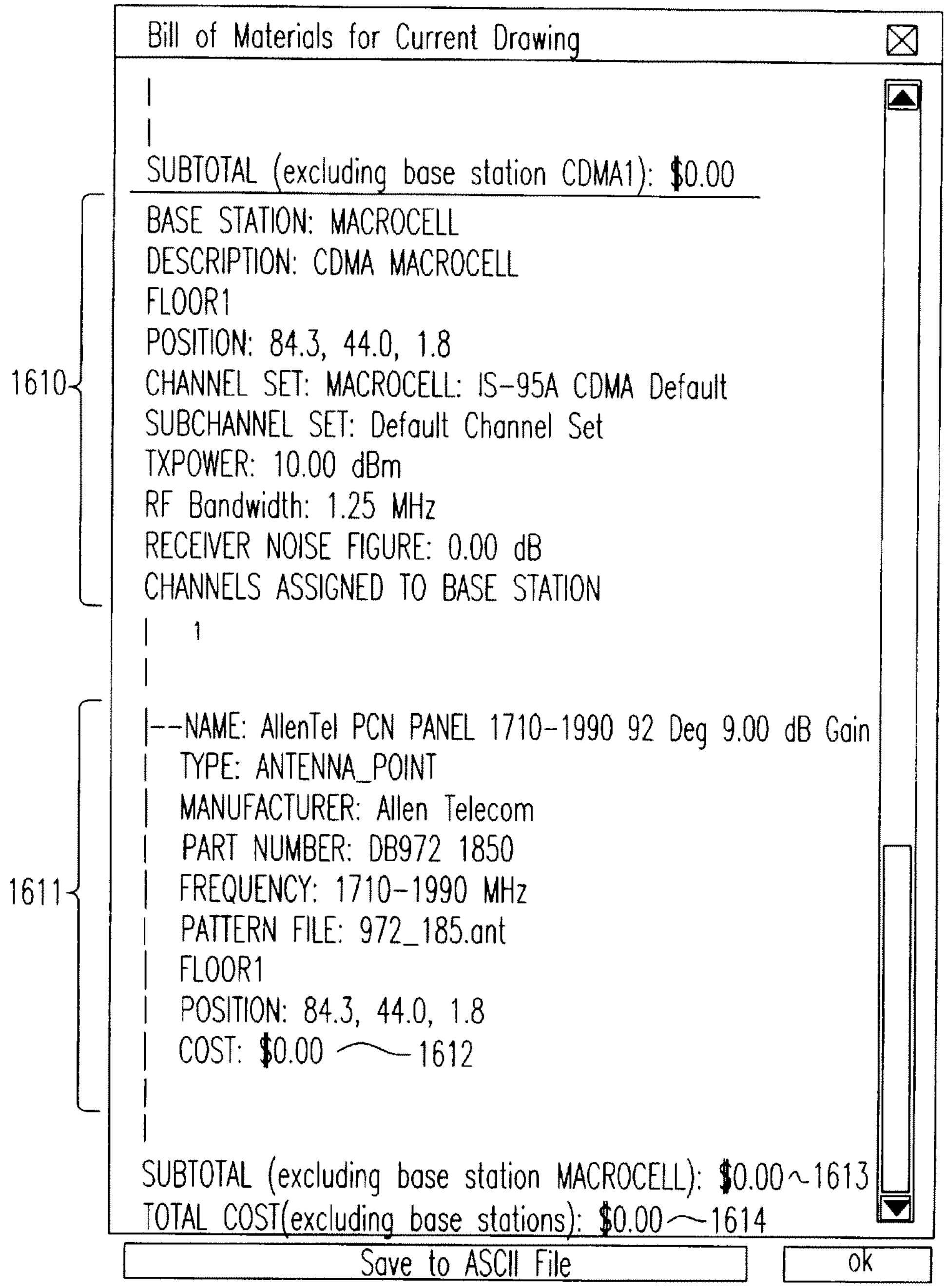

Bill of Materials for Current Drawing
|
|
SUBTOTAL (excluding base station CDMA1): $0.00
BASE STATION: MACROCELL
DESCRIPTION: CDMA MACROCELL
FLOOR1
POSITION: 84.3, 44.0, 1.8
CHANNEL SET: MACROCELL: IS-95A CDMA Default
SUBCHANNEL SET: Default Channel Set
TXPOWER: 10.00 dBm
RF Bandwidth: 1.25 MHz
RECEIVER NOISE FIGURE: 0.00 dB
CHANNELS ASSIGNED TO BASE STATION
| 1
|
|--NAME: AllenTel PCN PANEL 1710-1990 92 Deg 9.00 dB Gain
| TYPE: ANTENNA_POINT
| MANUFACTURER: Allen Telecom
| PART NUMBER: DB972 1850
| FREQUENCY: 1710-1990 MHz
| PATTERN FILE: 972_185.ant
| FLOOR1
| POSITION: 84.3, 44.0, 1.8
| COST: $0.00
|
|
SUBTOTAL (excluding base station MACROCELL): $0.00
TOTAL COST(excluding base stations): $0.00
Save to ASCII File
ok
1610
1611
1612
1613
1614

FIG.16

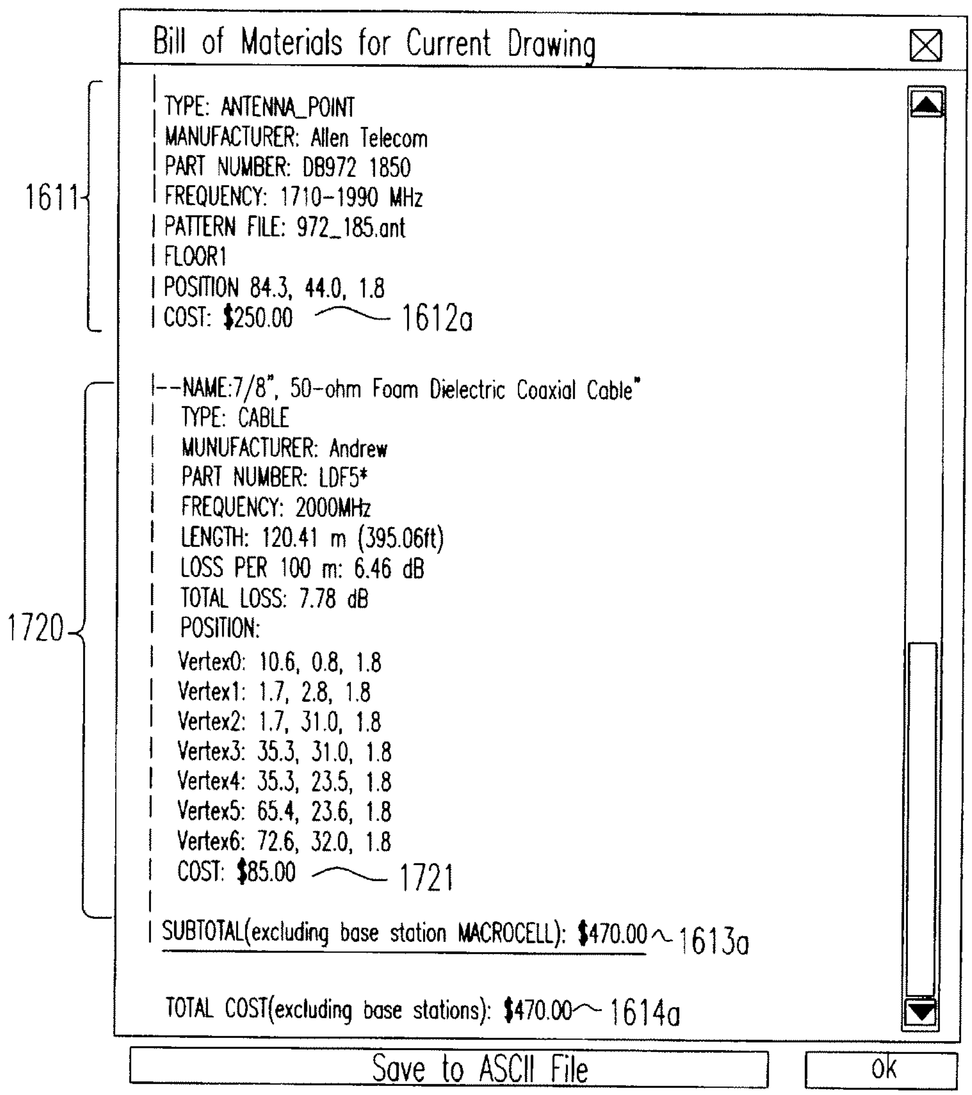

Bill of Materials for Current Drawing
TYPE: ANTENNA_POINT
MANUFACTURER: Allen Telecom
PART NUMBER: DB972 1850
FREQUENCY: 1710-1990 MHz
PATTERN FILE: 972_185.ant
FLOOR1
POSITION 84.3, 44.0, 1.8
COST: $250.00
1612a
1611
--NAME:7/8", 50-ohm Foam Dielectric Coaxial Cable"
TYPE: CABLE
MUNUFACTURER: Andrew
PART NUMBER: LDF5*
FREQUENCY: 2000MHz
LENGTH: 120.41 m (395.06ft)
LOSS PER 100 m: 6.46 dB
TOTAL LOSS: 7.78 dB
POSITION:
Vertex0: 10.6, 0.8, 1.8
Vertex1: 1.7, 2.8, 1.8
Vertex2: 1.7, 31.0, 1.8
Vertex3: 35.3, 31.0, 1.8
Vertex4: 35.3, 23.5, 1.8
Vertex5: 65.4, 23.6, 1.8
Vertex6: 72.6, 32.0, 1.8
COST: $85.00
1721
1720
SUBTOTAL(excluding base station MACROCELL): $470.00
1613a
TOTAL COST(excluding base stations): $470.00
1614a
Save to ASCII File
Ok

FIG.17

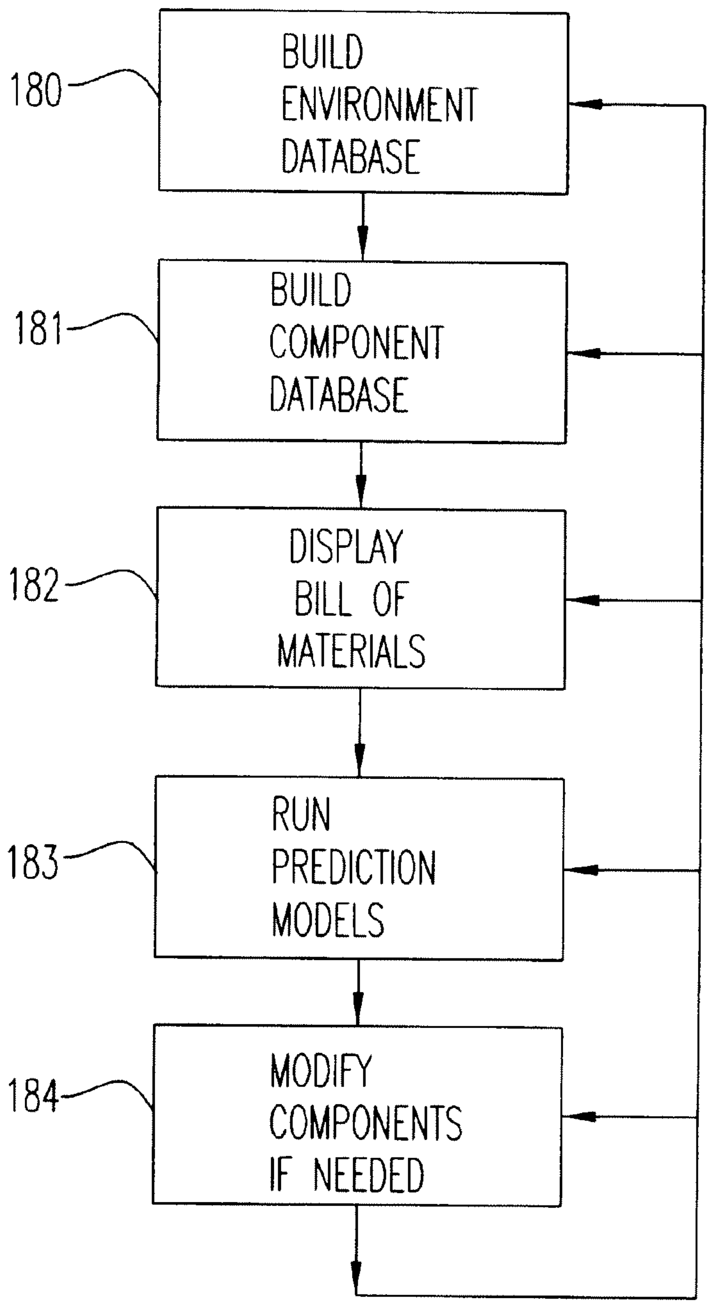

180
BUILD ENVIRONMENT DATABASE
181
BUILD COMPONENT DATABASE
182
DISPLAY BILL OF MATERIALS
183
RUN PREDICTION MODELS
184
MODIFY COMPONENTS IF NEEDED

FIG.18

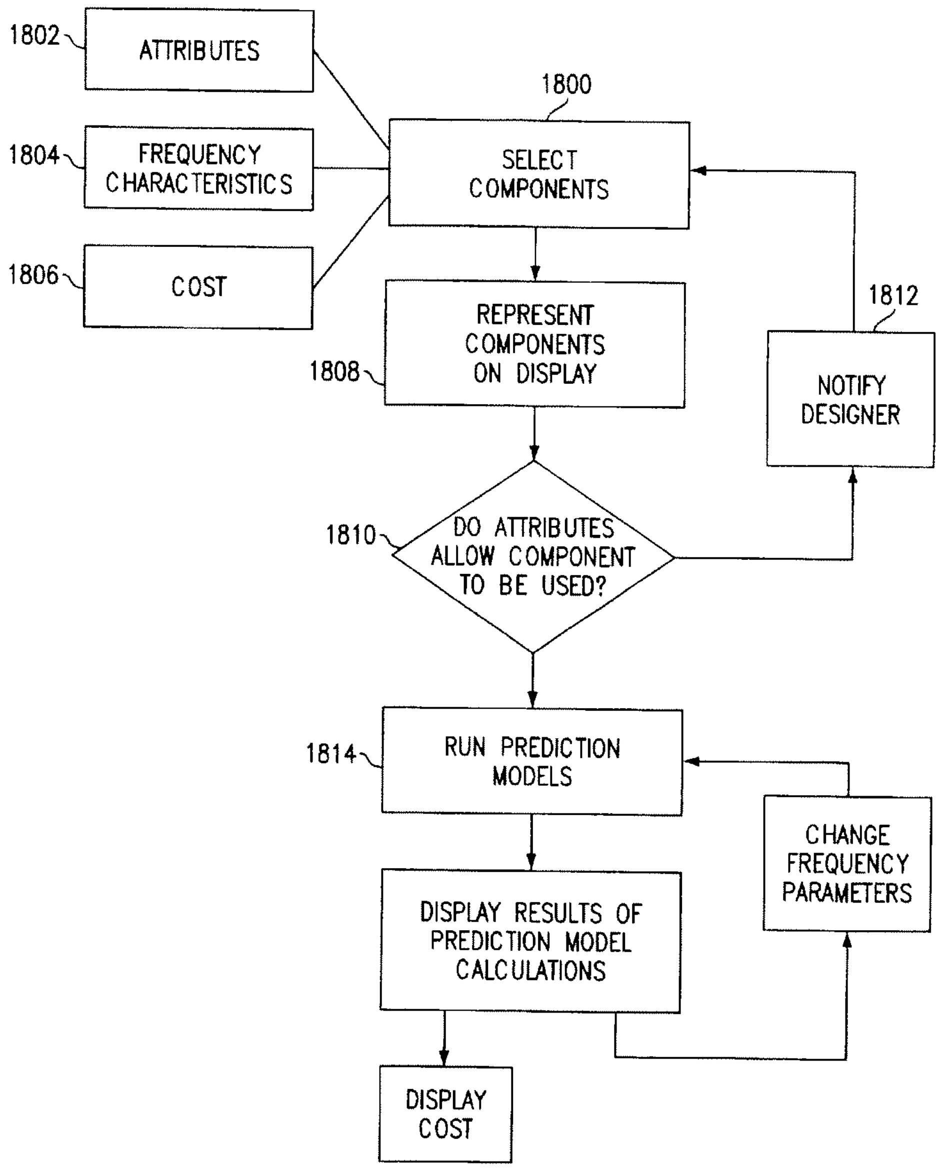

1802
ATTRIBUTES
1804
FREQUENCY CHARACTERISTICS
1806
COST
1800
SELECT COMPONENTS
REPRESENT COMPONENTS ON DISPLAY
1808
1812
NOTIFY DESIGNER
1810
DO ATTRIBUTES ALLOW COMPONENT TO BE USED?
1814
RUN PREDICTION MODELS
CHANGE FREQUENCY PARAMETERS
DISPLAY RESULTS OF PREDICTION MODEL CALCULATIONS
DISPLAY COST

FIG.19

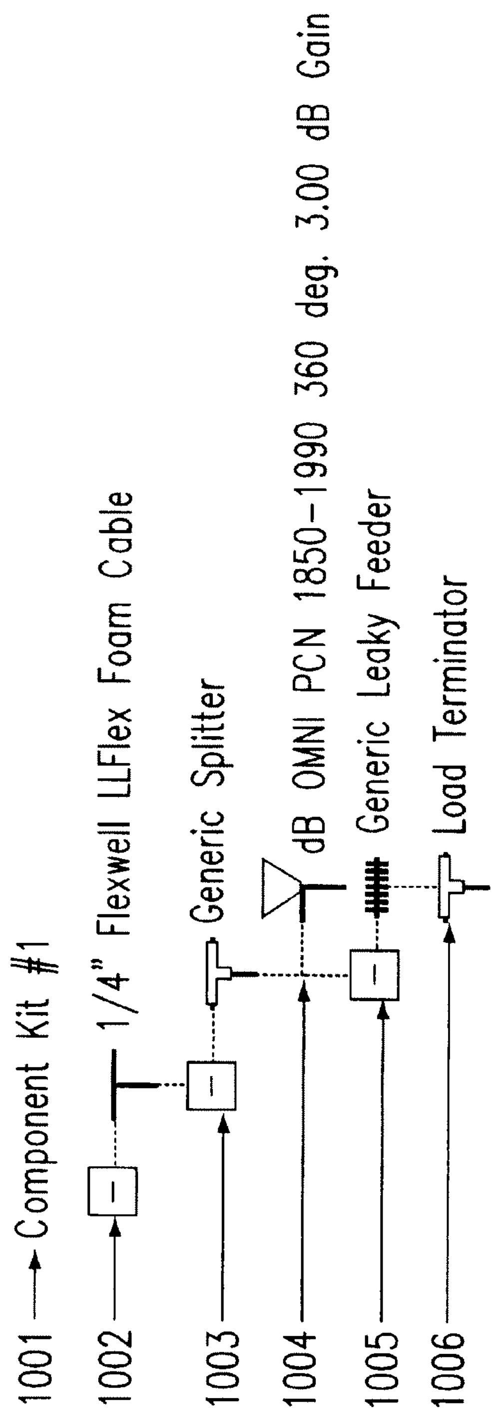

1001
Component Kit #1
1002
1/4" Flexwell LLFlex Foam Cable
1003
Generic Splitter
1004
dB OMNI PCN 1850–1990 360 deg. 3.00 dB Gain
1005
Generic Leaky Feeder
1006
Load Terminator

FIG.20

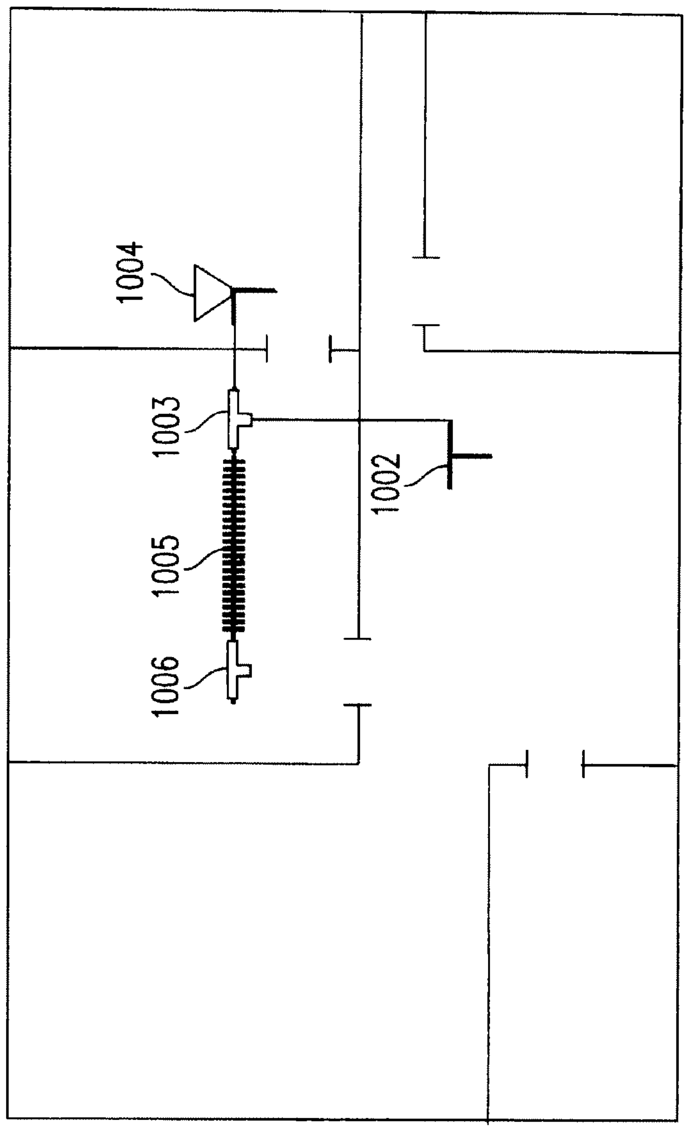


FIG.21

METHOD AND SYSTEM FOR DESIGNING OR DEPLOYING A COMMUNICATIONS NETWORK WHICH CONSIDERS FREQUENCY DEPENDENT EFFECTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to the U.S. patent application Ser. Nos. 09/352,678 filed Jul. 14, 1999, now U.S. Pat. No. 6,499,006; 09/318,840 filed May 26, 1999, now U.S. Pat. No. 6,317,599; 09/318,841 filed May 26, 1999; and 09/318,842 filed May 26, 1999, now U.S. Pat. No. 5,493,679; and is also related to the concurrently filed applications having U.S. Ser. Nos. 09/632,853, entitled "Method and System for Designing or Deploying a Communications Network which Considers Component Attributes"; and 09/633,133, entitled "Method and System for Designing or Deploying a Communications Network which Allows the Simultaneous Selection of Multiple Components", all of which are assigned to a common assignee, and the subject matter of these applications is incorporated herein by reference.

DESCRIPTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to engineering and management systems for the design of communications networks (both wireless and wired) and, more particularly, to a system and method for managing a real time bill of materials when designing, evaluating or optimizing the performance and/or costs of a communication system using a three-dimensional (3-D) representation of the environment. The present invention provides the design engineer with the ability to (1) group components together as a single connected or unconnected unit or "component kit" to simplify selection and assembly of hardware components, (2) have at his or her disposal in the Parts List Library performance parameters for selected components which are associated with the signal or "frequency" which will pass through the component such that electromechanical properties of the components can be considered on a frequency dependent basis automatically by the system, and (3) have at his or her disposal attributes which are associated with specific components in the Parts List Library which, acting in concert with real-time smart processing, provide the design engineer with notifications or warnings when he or she has proposed connections, components, or other arrangements which will not operate correctly in the communications network.

2. Background Description

As wireless communications use increases, radio frequency (RF) coverage within buildings and signal penetration into buildings from outside transmitting sources has quickly become an important design issue for wireless engineers who must design and deploy cellular telephone systems, paging systems, or new wireless systems and technologies such as personal communication networks or wireless local area networks. Designers are frequently requested to determine if a radio transceiver location, or base station cell site can provide reliable service throughout an entire city, an office, building, arena or campus. A common problem for wireless systems is inadequate coverage, or a "dead zone," in a specific location, such as a conference room. It is now understood that an indoor wireless PBX (private branch exchange) system or wireless local area network (WLAN) can be rendered useless by interference from nearby, similar systems. The costs of in-building and microcell devices which provide wireless coverage within a 2 kilometer radius are diminishing, and the workload for RF engineers and technicians to install these on-premises systems is increasing sharply. Rapid engineering design and deployment methods for microcell and in-building wireless systems are vital for cost-efficient build-out.

Analyzing radio signal coverage penetration and interference is of critical importance for a number of reasons. A design engineer must determine if an existing outdoor large scale wireless system, or macrocell, will provide sufficient coverage throughout a building, or group of buildings (i.e., a campus). Alternatively, wireless engineers must determine whether local area coverage will be adequately supplemented by other existing macrocells, or whether indoor wireless transceivers, or picocells, must be added. The placement of these cells is critical from both a cost and performance standpoint. If an indoor wireless system is being planned that interferes with signals from an outdoor macrocell, the design engineer must predict how much interference can be expected and where it will manifest itself within the building, or group of buildings. Also, providing a wireless system that minimizes equipment infrastructure cost as well as installation cost is of significant economic importance. As in-building and microcell wireless systems proliferate, these issues must be resolved quickly, easily, and inexpensively, in a systematic and repeatable manner.

There are many computer aided design (CAD) products on the market that can be used to design the environment used in one's place of business or campus. WiSE from Lucent Technology, Inc., SignalPro from EDX, PLAnet by Mobile Systems International, Inc., and TEMS and TEMS Light from Ericsson are examples of wireless CAD products. In practice, however, a pre-existing building or campus is designed only on paper and a database of parameters defining the environment does not readily exist. It has been difficult, if not generally impossible, to gather this disparate information and manipulate the data for the purposes of planning and implementation of indoor and outdoor RF wireless communication systems, and each new environment requires tedious manual data formatting in order to run with computer generated wireless prediction models. Recent research efforts by AT&T Laboratories, Brooklyn Polytechnic, and Virginia Tech, are described in papers and technical reports entitled "Radio Propagation Measurements and Prediction Using Three-dimensional Ray Tracing in Urban Environments at 908 MHZ and 1.9 GHz," (*IEEE Transactions on Vehicular Technology*, VOL. 48, No. 3, May 1999), by S. Kim, B. J. Guarino, Jr., T. M. Willis III, V. Erceg, S. J. Fortune, R. A. Valenzuela, L. W. Thomas, J. Ling, and J. D. Moore, (hereinafter "Radio Propagation"); "Achievable Accuracy of Site-Specific Path-Loss Predictions in Residential Environments," (*IEEE Transactions on Vehicular Technology*, VOL. 48, No. 3, May 1999), by L. Piazzi and H. L. Bertoni; "Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5.85 Ghz," (*IEEE Transactions on Communications*, Vol. 46, No. 11, November 1998), by G. Durgin, T. S. Rappaport, and H. Xu; "Radio Propagation Prediction Techniques and Computer-Aided Channel Modeling for Embedded Wireless Microsystems," ARPA Annual Report, MPRG Technical Report MPRG-TR-94-12, July 1994, 14 pp., Virginia Tech, Blacksburg, by T. S. Rappaport, M. P. Koushik, J. C. Liberti, C. Pendyala, and T. P. Subramanian; "Radio Propagation Prediction Techniques and Computer-Aided Channel Modeling for Embedded Wireless

Microsystems," MPRG Technical Report MPRG-TR-95-08, July 1995, 13 pp., Virginia Tech, Blacksburg, by T. S. Rappaport, M. P. Koushik, C. Carter, and M. Ahmed; "Use of Topographic Maps with Building Information to Determine Antenna Placements and GPS Satellite Coverage for Radio Detection & Tracking in Urban Environments," MPRG Technical Report MPRG-TR-95-14, Sep. 15, 1995, 27 pp., Virginia Tech, Blacksburg, by T. S. Rappaport, M. P. Koushik, M. Ahmed, C. Carter, B. Newhall, and N. Zhang; "Use of Topographic Maps with Building Information to Determine Antenna Placement for Radio Detection and Tracking in Urban Environments," MPRG Technical Report MPRG-TR-95-19, November 1995, 184 pp., Virginia Tech, Blacksburg, by M. Ahmed, K. Blankenship, C. Carter, P. Koushik, W. Newhall, R. Skidmore, N. Zhang and T. S. Rappaport; "A Comprehensive In-Building and Microcellular Wireless Communications System Design Tool," MPRG-TR-97-13, June 1997, 122 pp., Virginia Tech, Blacksburg, by R. R. Skidmore and T. S. Rappaport; "Predicted Path Loss for Rosslyn, Va.," MPRG-TR-94-20, Dec. 9, 1994, 19 pp., Virginia Tech, Blacksburg, by S. Sandhu, P. Koushik, and T. S. Rappaport; "Predicted Path Loss for Rosslyn, Va., Second set of predictions for ORD Project on Site Specific Propagation Prediction" MPRG-TR-95-03, Mar. 5, 1995, 51 pp., Virginia Tech, Blacksburg, by S. Sandhu, P. Koushik, and T. S. Rappaport. These papers and technical reports are illustrative of the state of the art in site-specific propagation modeling and show the difficulty in obtaining databases for city environments, such as Rosslyn, Va. While the above papers describe a research comparison of measured vs. predicted signal coverage, the works do not demonstrate a systematic, repeatable and fast methodology for creating an environmental database, nor do they report a method for analyzing system performance or visualizing and placing various wireless equipment components that are required to provide signals in the deployment of a wireless system in that environment.

While there are many methods available for designing wireless networks that provide adequate coverage, there is no easy method to ensure that the system will be cost effective. For instance, even though the coverage may be more than adequate, given the chosen wireless infrastructure components, the total cost of the system could be prohibitive.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a rapid and automated method for generating a bill of materials and cost information in real time, as components for a desired wireless communication system are specified and/or replaced by substitute components, while continuously predicting wireless system performance. This automatic method for comparing the cost and performance of competing products or competing design methodologies, in real time, offers a significant value for wireless engineers and provides a marked improvement over present day techniques.

It is another object of this invention to provide a communications design engineer with a software tools which allow him or her to (1) group components together as a single unit or "component kit" to simplify selection and assembly of hardware components, (2) have at his or her disposal in the Parts List Library performance parameters for selected components which are associated with the signal or "frequency" which will pass through the component such that electromechanical properties of the components can be considered on a frequency dependent basis either automatically or through the use of a prompt (i.e., these being "frequency dependent characteristics"), and (3) have at his or her disposal attributes which are associated with specific components in the Parts List Library which, acting in concert with real-time smart processing, provide the design engineer with notifications or warnings when he or she has proposed connections, components, or other arrangements which will not operate correctly in the communications network.

According to the invention, a design engineer builds a model of the desired wireless communications system and specifies each component necessary to provide sufficient or optimal system performance. A parts list is maintained, in real time, that contains a definition of each system component and its associated performance and cost parameters. Using this method, the user is able to rapidly change the physical location of components within the wireless system in order to investigate alternative designs which may use different components, such as antennas and cables; or use different RF distribution methods and/or various types of coaxial or optical splitter systems, etc. Cost parameters include both component costs and installation costs. As the system is changed through a series of "what-if" scenarios, components are replaced with substitute components, cable lengths are modified, antenna systems and base stations are re-positioned to alternate locations, etc.

Each time a component is added to or deleted from the system model, the bill of materials is automatically updated and component costs, total costs, and altered system performance specifications are immediately available to the design engineer. The designer may choose to swap components for less expensive components. The performance characteristics of the system are automatically updated as cost choices are made to enable the designer to assess the changes in performance and cost at the same time.

The communications design engineer may group several components together into a collection referred to as a "component kit". Thereafter, he or she will need only select the "component kit" for inclusion in the computerized representation of the physical environment in which the communications network will be installed. These "component kits" could be custom designed by the design engineer or, alternatively, the software package included in this system could have preselected components bundled as a "component kit". The "component kits" allow the design engineer to more simply and quickly prepare models of the communications network since he or she will be able to select essentially bundles of communications components at a time. The system; however, will be able to track all the attributes of all the components in the selected component kits, including all performance attributes, pricing information, and other physical attributes and maintenance schedules, such that calculations will automatically consider the performance criteria, pricing and compatibility for the system designed by the engineer. The component kits may be assembled in the same manner as an actual communication system, including the associated cabling and distribution system, so that connections between components are already set up when the kit is added into a system; this saves a great deal of time for the engineer.

Various attributes of components will be associated with specific components in the Parts List Library, such as, for example, whether a component is an optical component or one which requires radio signals. As another example, the length of cable in which a signal can propagate without unacceptable deterioration may be associated with the cable in the parts list library. These attributes will be considered automatically by the system of this invention such that when

a design engineer attempts to model connected components which are not properly connectable in the physical world, or when he or she attempts to use too long a cable length, etc., the system will provide a warning that the system being designed will be inoperative or be otherwise flawed. This will allow the designer to immediately recognize errors in design and correct for them during the design phase. Without such a facility, errors may not be discovered until installation or use of the system, at which point they are far more costly to repair.

Frequency dependent characteristics will also be associated with individual components in the Parts List Library. This will allow the design engineer to automatically consider the effects of signal frequency on the electrical performance of the designed communications network. This feature is especially valuable in light of the fact that most of said components are specifically designed to function in multiple frequency bands, with varying performance with respect to frequency.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, in which:

FIG. **1** shows an example of a simplified layout of a floor plan of a building;

FIG. **2** shows effective penetration of Radio Frequency (RF) transmission into a building from a macrocell;

FIG. **3** shows a simplified layout of a floor plan of a building including an outdoor macrocell and an indoor base station;

FIG. **4** shows the layout of FIG. **3**, but with a revised base station designed to eliminate interference;

FIG. **5** is a flow diagram of a general method used to design a wireless communication network;

FIG. **6** is a flow diagram of a method used to generate estimates based on field measurements;

FIG. **7** is a flow diagram of a method used to match best propagation parameters with measured data;

FIG. **8** is a flow diagram of a method for prediction;

FIGS. **9A** and **9B** together make up a detailed flow diagram of a method to generate a design of a wireless network and determine its adequacy;

FIG. **10** is a flow diagram showing a method for using watch points during antenna repositioning or modification;

FIG. **11** shows a simplified layout of a floor plan of a building with a base station and watch points selected;

FIG. **12** shows a dialog box displaying the locations of the selected watch points and choices for display information;

FIG. **13** shows a simplified layout of a floor plan of a building with a base station and initial RSSI values for the selected watch points;

FIG. **14** shows a simplified layout of a floor plan of a building with a repositioned base station and changed RSSI values for the selected watch points;

FIG. **15** shows a simplified layout of a floor plan of a building with a re-engineered base station and changed RSSI values for the selected watch points;

FIG. **16** shows a bill of materials summary for a drawing, according the preferred embodiment of the invention;

FIG. **17** shows a bill of materials summary for a drawing after costs have been added to a database, according the preferred embodiment of the invention;

FIG. **18** is a flow diagram showing the general method of the present invention;

FIG. **19** is a flow diagram showing the mechanisms for considering the effects of various attributes on and frequency characteristics on the communications system design, and, as required for notifying the designer of any inherent design flaws;

FIG. **20** is a computer display showing the assembly of a "component kit" according to the present invention; and

FIG. **21** is a schematic representation of a floor plan on which the components of a "component kit" have been displayed.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

Design of Wireless Communication Systems

Using the present method, it is now possible to assess the RF environment in a systematic, organized fashion by quickly viewing signal strength, or interference levels, or other wireless system performance measures. The current embodiment is designed specifically for use with the SitePlanner™ suite of products available from Wireless Valley Communications, Inc. of Blacksburg, Va. However, it will be apparent to one skilled in the art that the method could be practiced with other products either now known or to be developed in the future. (SitePlanner is a trademark of Wireless Valley Communications, Inc.)

Referring now to FIG. **1**, there is shown a two-dimensional (2-D) simplified example of a layout of a building floor plan. The method uses 3-D computer aided design (CAD) renditions of a building, or a collection of buildings and/or surrounding terrain and foliage. However, for simplicity of illustration a 2-D figure is used. The various physical objects within the environment such as external walls **101** internal walls **102** and floors **103** are assigned appropriate physical, electrical, and aesthetic values. For example, outside walls **101** may be given a 10 dB attenuation loss, signals passing through interior walls **102** may be assigned 3 dB attenuation loss, and windows **104** may show a 2 dB RF penetration loss. In addition to attenuation, the obstructions **101**, **102** and **103** are assigned other properties including reflectivity and surface roughness.

Estimated partition electrical properties loss values can be extracted from extensive propagation measurements already published, which are deduced from field experience, or the partition losses of a particular object can be measured directly and optimized instantly using the present invention combined with those methods described in the copending application Ser. No. 09/221,985, entitled "System for Creating a Computer Model and Measurement Database of a Wireless Communication Network" filed by T. S. Rappaport and R. R. Skidmore. Once the appropriate physical and electrical parameters are specified, any desired number of hardware components of RF sources can be placed in the 3-D building database, and received signal strengths (RSSI), network throughput, bit or frame or packet error rate, network delay, or carrier-to-interference (C/I), carrier-to-noise (C/N), or chip energy to interference (Ec/Io) ratios can be plotted directly onto the CAD drawing. The 3-D environment database could be built by a number of methods, the preferred method being disclosed in the concurrently filed, copending application Ser. No. 09/318,841. Traffic capacity analysis, frequency planning, co-channel interference analysis can be performed in the invention along with RF coverage. Other system performance metrics may be easily incorporated by one skilled in the art through well known equations.

FIG. 2 depicts effective RF penetration into the building from the distant macrocell using a close-in virtual macrocell transmitting into the lossless distributed antenna.

Referring to FIG. 2, there are several windows **104**, and even a large glass foyer **105**, on the north wall of the building, so RF penetration into this part of the building is quite good, as shown by contour lines **108** and **109** for 0 dB and −30 dB, respectively. Even so, interior walls **102** cause signal levels in some areas to drop below a minimum useable signal strength of about −90 dBm, especially in some of the southern rooms, as shown by contour line **110**. Consequently, macrocell coverage there will probably be poor.

Other outdoor macrocells can be modeled in the same way, and their signal strength contours plotted, to determine if hand-offs can compensate for the inadequacies of the macrocell north of the building. If not, then indoor picocells (and their distributed feed systems, antennas, and antenna patterns) can be easily added if necessary, and their performance checked using the method, to complement coverage provided by the macrocells.

The mathematical propagation models used to predict and optimize antenna positioning in a desired environment may include a number of predictive techniques models, such as those described in the previously cited and following technical reports and papers: "Interactive Coverage Region and System Design Simulation for Wireless Communication Systems in Multi-floored Indoor Environments, SMT Plus," *IEEE ICUPC '96 Proceedings*, by R. R. Skidmore, T. S. Rappaport, and L. Abbott which is hereby incorporated by reference. Some simple models are also briefly described in "SitePlanner 3.16 for Windows 95/98/NT User's Manual" (Wireless Valley Communications, Inc. 1999), hereby incorporated by reference. It would be apparent to one skilled in the art how to apply other system performance models to this method.

Interference, instead of radio signal strength, is the dominant performance-limiting factor in many situations due to increased wireless communications use. Modeling interference from any source to an established or contemplated wireless system is straightforward using the method. Suppose, for example, that an indoor wireless communication system is assigned a frequency set identical to that of an outdoor wireless system. Although the indoor system may provide sufficient RSSI throughout its coverage area, interference from the outside system may still render the indoor wireless system ineffectual in certain parts of the building.

Caution must be used, however, when modeling and analyzing interference, since the detrimental effect may also depend upon technologies and/or signal processing technologies, not just signal power levels. For example, a geographic area could have similar narrowband and/or wideband in the 800 MHZ cellular bands, for instance with Advanced Mobile Phone System (AMPS) and Code Division Multiple Access (CDMA) systems, but users using either technology may be able to coexist if their respective demodulation processes reject interference provided by the undesired system. The current embodiment of this invention allows the user to select the air interface/technology being used by the wireless system being designed and automatically adjusts the prediction of interference accordingly.

FIG. 3 shows another rendition of the office building example, but an indoor wireless system **107** has been added. In this example, 800 MHZ AMPS technology is assigned to both transmitters **106** and **107**. Differing wireless standards and technologies such as CDMA and Global System Mobile (GSM) could have been selected as well. The present invention uses a database to represent the exact physical air interface standards of a wide range of technologies and may be easily edited for future interface standards. As new technologies are developed, one skilled in the art could easily modify this invention to include the new technologies.

The outdoor wireless system **106** is now interfering with the indoor network, and the effect is checked by plotting C/I contours **111** and **112** at 0 dB and −30 dB, respectively, for the outdoor system and also plotting C/I contours **113** and **114** at 0 dB and −30 dB for the indoor system. The 0 dB contour **114** shows where the desired and interfering signal levels are equal, so the interfering outdoor system's signal predominates in areas outside this contour. It is obvious that the indoor network is rendered useless throughout many parts of the building. There are a number of possible solutions that may be analyzed by a designer using the present invention.

One solution is to change the indoor system's antenna location or increase the transmitted power, add more nodes, or select a different frequency set. These changes may be made with the simple click of a mouse in the method of the invention, so that new channel sets, antenna locations, or alternative antenna systems (such as in-building distributed systems, directional antennas, or leaky feeders) may be evaluated quickly, thereby eliminating guesswork and/or costly on-site experimentation with actual hardware. Instead of displaying contours of coverage or interference, the present invention also allows the user to specify fixed or moveable watch points that indicate or display predicted performance in extremely rapid fashion at specific points in the environment.

For example, FIG. 4 illustrates how the same indoor wireless system of FIG. 3 can provide adequate C/I protection when connected to a distributed indoor antenna system consisting of a two-way splitter **401** (3 dB loss+insertion loss) and two 40 foot cable runs **402** to popular commercial indoor omnidirectional antennas **403**. A look at the new 0 dB contour lines **111** and **215**, and −30 dB contour lines **112*a*** and **216** show that the coverage inside the building is now adequate; the outdoor system **106** no longer causes significant interference in most parts of the building. Watch points allow a user to instantly determine spot coverage or other system performance without having to wait for the computation and display of contour plots.

The method allows any type of distributed antenna system to be modeled within seconds, while continuously monitoring and analyzing the component and installation cost and resulting link budget, as disclosed below, enabling "what-if" designs to be carried out on the fly with minimum guess work and wasted time. It is clear that while an RF system is shown and described herein, the same concepts may be applied to any communications network, with a wide range of distribution methods and components.

In the present embodiment of the invention, the designer identifies locations in the 3-D environmental database where certain levels of wireless system performance are desirable or critical. These locations, termed "watch points", are points in three-dimensional space which the designer identifies by visually pointing and/or clicking with a mouse or other input device at the desired location in the 3-D environmental database. Any number of such watch points may be placed throughout the 3-D environment at any location. Watch points may be designated prior to performing a performance prediction on a given wireless communication system, or may be dynamically created by the user at any

time during the course of a wireless system performance calculation using the same point and click technique described above.

Watch points provide graphical and/or textual feedback to a designer regarding the wireless system performance throughout the environment. Depending on the type of visual feedback desired by the designer, watch points may take the form of one or more of the following:

A computed number displayed as text that represents received signal strength (RSSI), signal-to-interference ratio (SIR), signal-to-noise ratio (SNR), frame error rate (FER), bit error rate (BER), or other wireless system performance metrics;

A small region of solid color whose shade and/or tint varies relative to some computed wireless system performance metric;

Colored lines linking the watch point location with the location one or more antennas in the wireless communication system, where the color, thickness, and/or other physical aspect of the connecting line varies relative to some computed wireless system performance metric and dependent upon whether the forward or reverse wireless system channel is being analyzed;

Other form designated by the designer; or

Any combination of the above.

In all cases, the graphical and/or textual representation of each watch point is updated in real-time as a result of the instantaneous computation of the wireless system performance metrics, which are linked to the 3-D environmental database, and initiated due to dynamic changes being made to the wireless system configuration and/or watch point position itself by the user. For example, if the user repositions an antenna using the mouse or other input device, the effect of doing so on the overall wireless system performance is computed and the results are displayed via changes in the appearance of watch points. In addition, numerical values predicted at the watch points are displayed in summary in a dialog window and written to a text file for later analysis. This process is described in greater detail in the following sections.

The preferred embodiment of the invention utilizes a 3-D environmental database containing information relevant to the prediction of wireless communication system performance. This information includes but is not limited to the location, and the physical and electromagnetic properties of obstructions within the 3-D environment, where an obstruction could be any physical object or landscape feature within the environment (e.g., walls, doors, windows, buildings, trees, terrain features, etc.), as well as the position and physical and electrical properties of communications hardware to be used or simulated in the environment.

The designer identifies the location and type of all wireless communication system equipment within the 3-D environmental database. This point-and-click process involves the designer selecting the desired component from a computer parts database and then visually positioning, orienting, and interconnecting various hardware components within the 3-D environmental database to form complete wireless communication systems. The preferred embodiment of the computer parts database is more fully described below. The resulting interconnected network of RF hardware components (commonly known as a wireless distributed antenna) is preferably assembled using either a drag and drop technique or a pick and place and is graphically displayed overlaid upon the 3-D environmental database, and utilizes electromechanical information available for each component via the parts list library in order to fully describe the physical operating characteristics of the wireless communication system (e.g., the system noise figure, antenna radiation characteristics, frequencies, etc.). This information is directly utilized during the prediction of wireless system performance metrics and is discussed later.

The present invention represents a dramatic improvement over prior art by providing the design engineer with instant feedback on wireless system performance metrics as the user alters the physical location of switches, routers, repeaters, transducers, couplers, transmitters, receivers, and other components described elsewhere or which would be known by those of skill in the art, or otherwise modifies the antenna system. The current embodiment utilizes the concept of watch points to implement this. Multiple methods of display and a wide range of settings are available for the designer to use in optimizing antenna placement based upon wireless system performance values displayed at each watch point. One skilled in the art could see how watch points as they are herein described could apply to different implementations as well. Descriptions of the different techniques implemented in the current invention are provided in the following sections.

One form of the method allows the designer to dynamically alter the position, orientation, and/or type of any hardware component utilized within a wireless communication system modeled in a 3-D environmental database. Using this technique, the designer may identify watch points representing critical areas of the 3-D environment that require a certain level of wireless system performance. Such areas could include the office of the Chief Executive Officer (CEO) of a company, a conference room, a city park, or the office of a surgeon on call. Next the designer selects the component of interest within the wireless system. In the present invention, this would be the selection of an antenna or leaky feeder antenna, for example, but one skilled in the art could see that this could be any physical antenna system component. Once the desired hardware component is selected, the designer may begin making changes to the state of the component. For example, by moving the mouse or other input device cursor, the user could effectively relocate the selected component to another position in the 3-D environmental database. This involves the user visually moving the mouse cursor, in real-time, such that the cursor resides in another portions of the 3-D database. The present invention recalculates wireless system performance based upon RSSI, SIR, SNR, FER, BER, or other metric, incorporating the user's desired change in the position of the selected component.

The calculations combine the electromechanical properties of each component in the wireless communication system (e.g., noise figure, attenuation loss or amplification, antenna radiation pattern, etc.), the electromagnetic properties of the 3-D environmental database, and radio wave propagation techniques (detailed later) to provide an estimate of the wireless system performance. Calculations are performed at each watch point the user has identified, and the graphical display of the watch point is updated to reflect the result of the calculations.

As the user moves the mouse cursor and effectively repositions the selected component, the overall performance of the wireless communication system may be altered. For example, if the selected component is an antenna, repositioning the antenna changes the origination point of radio wave signals being broadcast from the antenna, and can thus dramatically change the reception of adequate RF signal throughout the environment. Because the graphical display

of the watch points is updated in real-time as the selected component is repositioned, the designer is provided instant feedback on the revised wireless system performance, and can make design decisions based upon the viability of multiple proposed locations and/or wireless system configurations rapidly. While many of the concepts discussed above deal with wireless networks, one of ordinary skill in the art would understand that similar features may be implemented for optical, infrared, or baseband networks that use fixed or portable terminals.

In addition to the functionality described above, the designer is free to add additional watch points in any location within the 3-D environmental database at any time during a communication system performance prediction. In the current implementation, the designer clicks with the mouse or other input device on the desired location in the 3-D environmental database to create a new watch point at the selected location that is then updated throughout the remainder of the performance prediction.

In a similar fashion, the preferred embodiment enables a designer to reorient a selected antenna in real-time with respect to any coordinate axis while the graphical display of all drawing watch points is updated to reflect the revised wireless system performance metrics as a result of the new antenna orientation.

In a similar fashion, a designer may replace an existing hardware component in the wireless communication system with any component available from the parts list library. In doing so, the changes to the wireless communication system performance as a result of the replacement is reflected in the graphical display of the watch points.

In a similar fashion, a designer may selectively include or exclude any subset of components within the wireless communication system while selecting components to involve in the wireless system performance calculation. For example, a designer could consider the effect of repositioning a single antenna, or could consider the combined, composite effect on the watch points as individual antennas are repositioned within a wireless system network consisting of additional, fixed antenna placements.

In a similar fashion, the designer may choose to allow watch points to be mobile. That is, instead of positioning a watch point and having the graphical display of the watch point reflect the changing wireless system performance metric, the designer could instead identify a watch point whose position is mobile but whose graphical display remains constant. In this scenario, the position of the watch point fluctuates along a linear path traced between itself and the current location of the mouse cursor until a position within the 3-D database is found at which the desired level of wireless system performance metric is maintained. For example, the designer may create a watch point to maintain a constant graphical display synonymous with −65 dBm RSSI. As the user repositions, reorients, or otherwise alters components within the wireless communication system, the watch point alters its position within the 3-D environmental database until a position is found at which a calculated value of −65 dBm RSSI is determined.

In addition to enabling a designer to reposition, reorient, and/or replace wireless system components in real-time while visualizing the impact of such changes at selected watch points within the 3-D database, the user may choose to maintain the current configuration of the wireless communication system and instead create a single, mobile watch point. The watch point thus created is dynamically repositioned within the 3-D environmental database in real-time by the user by simply repositioning the mouse cursor.

Positioning the mouse cursor at a given location within the 3-D environmental database is equivalent to repositioning the watch point to match that location. In the present invention, this technique is used to allow the mobile watch point to represent a mobile user in the 3-D environmental database. As in the previous scenarios, the graphical display of the watch point is updated in real-time to reflect predicted wireless system performance metrics at the watch point position. The designer is free to select individual subsets of wireless system components to involve in the calculations of wireless system performance. Thus the graphical display of the watch point may reflect the performance metrics specific to individual wireless system components or the composite performance metrics due to the combined effect of multiple selected components. For example, the radiating power of multiple antennas can be combined into a single measure of received signal strength.

The two primary uses of the single mobile watch point technique involve the analysis of the forward link (or down link) and reverse link (or up link) of the wireless system. The forward link of a wireless communication system involves the flow of radio signals from the fixed wireless system to the mobile user, while the reverse link of a wireless communication system involves the flow of radio signals from the mobile user to the fixed wireless system. In the present embodiment, line segments are drawn between the mobile watch point (which is also the mouse cursor) to each antenna the designer has included in the wireless system performance prediction. In addition, the individual or subsets of antennas identified as having the best wireless system performance characteristics are differentiated from the other antennas by altering the color and/or other physical appearance of the connector lines between the antennas and the watch point. As the designer then repositions the mouse cursor, the selected location for the watch point in the 3-D database, and therefore the effective location of the mobile user, is adjusted to match that of the mouse cursor. The wireless system performance metrics are recalculated at the watch point location for the antenna components selected by the designer, and the graphical display of the watch point and all connector lines is updated accordingly.

Another improvement over the prior art is the ability to dynamically model the repositioning of leaky feeder antennas and visualize the effects on wireless system performance. A leaky feeder antenna can be thought of as a cable with many holes regularly spaced along its length. Such a cable would experience a signal loss or emanation at every hole and would thus radiate RF energy along the entire cable length. Leaky feeder antenna, or lossy coaxial cable as it is sometimes referred, can be thought of as analogous to a soaker hose where water flows in at the head of the hose and leaks out through a series of holes. The present method allows the designer to dynamically re-position a portion of the leaky feeder antenna and see in real time the effects on wireless system performance at the specified watch points. In the preferred embodiment, distributed antenna systems can be analyzed in terms of the contributions of individual antennas or collections of antennas taken as a whole, providing "composite" results in the latter case.

Referring to FIG. **5**, there is shown the general method of the invention. Before one can run an automated predictive model on a desired environment, a 3-D electronic representation of that environment must be created in function block **10**. The preferred method for generating a 3-D building or environment database is disclosed in the concurrently filed, copending application Ser. No. 09/318,841. The resulting definition utilizes a specially formatted vector database

format and comprises lines and polygons rather than individual pixels (as in a raster format). The arrangement of lines and polygons in the database corresponds to obstructions/partitions in the environment. For example, a line in a database could represent a wall, a door, tree, a building wall, or some other obstruction/partition in the modeled environment.

From the standpoint of radio wave propagation, each of the obstruction/partition in an environment has several electromagnetic properties. When a radio wave signal intersects a physical surface, several things occur. A certain percentage of the radio wave reflects off of the surface and continues along an altered trajectory. A certain percentage of the radio wave penetrates through or is absorbed by the surface and continues along its course. A certain percentage of the radio wave is scattered upon striking the surface. The electromagnetic properties given to the obstruction/partitions define this interaction. Each obstruction/partitions has parameters that include an attenuation factor, surface roughness, and reflectivity. The attenuation factor determines the amount of power a radio signal loses upon striking a given obstruction. The reflectivity determines the amount of the radio signal that is reflected from the obstruction. The surface roughness provides information used to determine how much of the radio signal is scattered and/or dissipated upon striking an obstruction of the given type.

Once this 3-D database of obstruction data has been built, the design engineer performs computer aided design and experimentation of a wireless network to be deployed in the modeled environment in function block **11**, to be described later. Cost and wireless system performance target parameters, transmitters, channel lists, placement options and antenna systems are all taken into account by the present invention.

In order to fine tune the experimental predictions, RF measurements may be optionally taken in function block **12**. A preferred method for collecting RF measurements is disclosed in copending application Ser. No. 09/221,985, supra. If necessary, database parameters that define the partition/obstruction characteristics may be modified using RF measurements as a guide to more accurately represent the modeled 3-D environment in function block **13**.

The results of the predictive models may be displayed in 3-D overlaid with the RF measurement data, if any, at any time in function block **14**. The design engineer analyzes the differences in the predicted and actual measurements in function block **15**, and then modifies the RF predictive models, if needed, in function block **16**. If necessary, the 3-D environment database may be modified based on the actual measurements to more accurately represent the wireless system coverage areas in function block **10**, and so on iteratively until done. The designer can optionally continue with any other step in this process, as desired.

The method of invention may be used in a variety of ways depending on the goals of the design engineer. FIG. **6** shows a variant on the above method used to generate estimates based on RF measurements. A 3-D database of the environment must still be generated in function block **10**. Field measurements are collected in function block **12**. The RF measurement data are then incorporated into the drawing of the environment in function block **61**. The design engineer may then generate estimates of power level and location of potential transmitters in function block **62**.

FIG. **7** shows a variant of the method used to achieve optimal prediction accuracy using RF measured data. Once again, a 3-D database of the environment is generated in function block **10**. However, before collecting field measurements, the design engineer creates a channel plan with "virtual" macrocell locations and power levels in function block **71**. The field measurements are then collected in function block **12** and the "virtual" locations of interfering transmitters can be determined in function block **72**. The best propagation parameters are then matched with measured data from the interferers in function block **73**.

A more detailed description of the method for prediction used in the present invention is now described. Referring to FIG. **8**, the 3-D environment definition is input in function block **801**. The first step required before predicting the performance of the wireless communication system is to model the wireless system with the 3-D environment. Antennas and types of related components and locations are selected in function block **802**. The desired antennas are chosen from a parts list of wireless hardware devices that may include a variety of commercially available devices. Each antenna is placed at a desired location within the environment, for instance, in a specific room on a floor of a building or on a flag pole in front of a building. A number of other components may be created and placed either within or connected to each antenna system. These components include, but are not limited to: cables, leaky feeder antennas, splitters, connectors, amplifiers, or any other user defined component.

FIGS. **9A** and **9B** show a method for adding antenna systems to a desired environment and generally for running trade-off analyses. First, the designer positions and defines outdoor wireless communication systems, if necessary in function block **901**. Next, the designer positions and defines indoor base stations in function block **902**. The methods of function blocks **901** and **902** differ in that the components of indoor wireless system will typically be different than an outdoor wireless system. In both cases, the designer is guided through a series of pull down menus and point-and-click options to define the location, type of hardware components and associated performance characteristics of the antenna systems. This data is stored in a database, that also contains cost and manufacturing specific information to produce a complete Bill of Materials list automatically, to be viewed at any time.

In order to fully describe a communication system in a newly created (or to be modified) wireless or wired system, the designer specifies the air interface/technology and frequencies associated with network protocol, physical media, or a network such as a wireless system in function block **903**. For a wireless system, the designer then lays out the full antenna system for the wireless network in function block **904**. Components such as base stations, cabling, connectors, amplifiers and other items of the antenna system are then selected from a parts list library containing information on commercially available hardware components in function block **905**. Next, the air interface and technology specific parameters are assigned and channel frequencies are customized for the wireless system in function block **906**. The channel frequencies are selected from pre-assigned channel clusters and assigned to the wireless system in function block **907**. An antenna system is then configured in function block **908**, selecting antennas from the parts list library as described above. The antennas are placed on the floor plan in function block **909** using a point and click of a mouse or other positioning device to visually place each component in the 3-D database.

At this or any time after a component has been placed on a floor, the designer may view a bill of materials in function block **910**. If necessary, the parts list may be modified to add or delete components or modify a component's cost or

performance characteristics in function block **911**. Components may be replaced or swapped for similar components for a quick trade-off analysis of both wireless system performance and overall cost in function block **912**. Components may be added, deleted or modified to more fully define the wireless communications system in function block **913**. The designer may redisplay the view of the environment including the wireless communication system, RF measurement data, and/or wireless system predicted performance results in a variety of forms, including 2-D, 3-D wireframe, 3-D wireframe with hidden lines, 3-D shaded, 3-D rendered or 3-D photorealistic rendering, at any time in function block **914**.

Typically, a designer will add network system components in succession, where each newly placed system component connects to a previously positioned component in the network. For a wireless network, one should note that cables and leaky feeder antennas are defined by a series of vertices connected by lines representing lengths of cabling as they are placed on a floor. This is also done for fiber optic and baseband cables. Cables and leaky feeders may also stretch vertically across building floors, down the sides of buildings, through elevator shafts, etc., simply by adding a vertex in the cable, changing the vertical height, and then continuing to place cable in new locations, in function block **915**. The designer does not need to manipulate a 3-D view of the environment and attempt to guide the cables vertically in the 3-D model. The designer may repeat any of the steps in this process, in any order, in the present invention.

Referring again to FIG. **8**, once the 3-D environment has been defined and antennas, cables and other objects which are used in network design have been selected and located, the wireless system performance prediction models may be run in function block **803**. A variety of different such models are available and may be used in succession, or alone to generate a sufficient number of "what-if" scenarios for predicting and optimizing of antenna placements and component selections.

Referring to FIG. **10**, a method for predictive modeling according the invention is shown. First, the designer selects the desired wireless system performance prediction model in function block **1001**. Preferred models are:

Wall/floor Attenuation Factor, Multiple Path Loss Exponent Model,

Wall/floor Attenuation Factor, Single Path Loss Exponent Model,

True Point-to-Point Multiple Path Loss Exponent Model,

True Point-to-Point Single Path Loss Exponent Model,

Distance Dependent Multiple Breakpoint Model,

Distance Dependent Multiple Path Loss Exponent Model,

Distance Dependent Single Path Loss Exponent Model, or other models as desired by the design engineer.

Also, models for propagation of optical and baseband signals, such as loss, coupling loss, distance-dependent loss, and gains are contemplated.

The physical and electrical properties of obstructions in the 3-D environment are set in function block **1002**. Although not all parameters are used for every possible predictive model, one skilled in the art would understand which parameters are necessary for a selected model. Parameters that may be entered include:

Prediction configuration—RSSI, C/I, and/or C/N (carrier to noise ratio);

Mobile Receiver (RX) Parameters—power, antenna gain, body loss, portable RX noise figure, portable RX height above floor;

Propagation parameters
- Partition Attenuation Factors
- Floor Attenuation Factors
- Path Loss Exponents
- Multiple Breakpoints
- Reflectivity
- Surface Roughness
- Antenna Polarization

other parameters as necessary for a given model The designer may save sets of physical, electrical and aesthetic parameters for later re-use. If such a parameter set has been previously saved, the designer may load that set in function block **1003**, thereby overwriting any parameters already in selected.

A designer then may select a number of watch points in function block **1004** to monitor for wireless system performance. Referring now to FIG. **11**, there is shown a simplified layout of a floor plan with a base station **1100**. The designer may use a mouse or other positioning device to point and click to any number of locations in the floor plan to select critical areas, or watch points, for monitoring. Here, for instance, four watch points **1101**, **1102**, **1103** and **1104** have been selected.

FIG. **12** shows a display, that lists by location, watch points selected for the current prediction. The designer may then select predictions for RSSI, signal to interference ratio (SIR) or signal to noise ratio (SNR). In addition, the designer can see changes in predicted values for each watch point in real time as the mouse is moved, or can choose to select new antenna positions specifically by clicking on a new location. As the designer repositions the mouse cursor, the antenna(s) selected prior to initiating the prediction are effectually repositioned and/or relocated according to position of the cursor. Once all watch points are selected, the prediction model is run. An alternative embodiment is that watch points could be entered and modified on the fly, as the prediction model is being run, rather than defined only prior to running the model. Another alternative embodiment is that RF values at the watch points are updated continuously as the mouse is repositioned, without a click being necessary.

FIG. **13** shows the floor plan of FIG. **11** with the initial RSSI values for each watch point **1101**, **1102**, **1103** and **1104** also shown. The designer may move the antenna **1100** to a new location and monitor the same watch points for coverage. FIG. **14** shows the floor plan of FIGS. **11** and **13** with the antenna **1100** moved to a new location **1400**. The RSSI values at each watch point **1101**, **1102**, **1103**, and **1104** are automatically updated with values associated with the new location of the antenna. Alternatively, the designer may choose to modify the components within the antenna system **1100** for performance or cost reasons. FIG. **15** shows the floor plan of FIGS. **11** and **13** with a base station **1100***a* at the same location, but with a higher performance antenna component. The RSSI values at each watch point **1101**, **1102**, **1103**, and **1104** are again automatically updated with values associated with the new wireless system performance parameters.

Referring again to FIG. **10**, for RF coverage models, the coverage areas and values are displayed in function block **1005**. If so desired, the designer modifies the electrical parameters of the obstructions, or modified components of antenna systems, or modifies antenna system locations or orientation, etc. in function block **1006** before running another prediction model in function block **1001**.

Referring again to FIG. **8**, after running a number of models, the design engineer may determine that RF coverage is optimal in decision block **804**. If so, then depending

on the results either a change in the location of antenna(s) and components will be desired or possibly just a substitution of components without a location change. For instance, even though the coverage may be more than adequate, the total cost of the wireless system could be prohibitive. A method for optimizing the costs using a dynamic, real time, bill of materials management system is disclosed below. Regardless, if the wireless network as currently modeled is not deemed optimal, then the method would continue again in function block **802** to re-select the components.

Once the design is as desired, then the 3-D database holds all of information necessary to procure the necessary components in the Bill of Materials. The locations of each component are clearly displayed, and a visual 3-D representation can be viewed as a guide.

Once the communications system design is as desired, the database holds all of information necessary to procure the necessary components in the Bill of Materials. The locations of each component are clearly shown, overlaid with the physical environment, and a visual 3-D representation can be viewed as a guide.

Generating and Managing a Bill of Materials

As described above, in more detail, the invention uses 3-D computer aided design (CAD) renditions of a building, collection of buildings, or any other such environment that contains information suitable for the prediction of a communications system performance. In an RF system, estimated partition electrical properties can be extracted from radio frequency measurements already published, and/or specified by the designer at any time. Once the appropriate electrical properties are specified, an unlimited number of RF sources can be placed in the 3-D database, and received signal strengths intensity (RSSI) or carrier-to-interference (C/I) ratios can be plotted directly onto the CAD drawing.

The 3-D environment database could be built by a number of methods, the preferred method being disclosed in the co-pending application Ser. No. 09/318,841. Traffic capacity analysis, frequency planning, and Co-channel or adjacent channel interference analysis can be performed concurrently with the prediction of RSSI, C/I and other wireless system performance measures. The antenna system and bill of materials could be built by a number of methods. The preferred method for building the antenna system is described above.

As the designer builds a model of a wireless communications system in a specified environment, as described above, a full bill of materials is maintained for every drawing in the environment. That is, each drawing may contain its own unique set and arrangement of antennas, feed systems and related components representing a variation in the design of a wireless communication system. These components are drawn from a global parts list library. A number of methods could be used to generate the global parts list library, and it would be apparent to one skilled in the art that varying formats could be used.

In the present invention, the design engineer selects a specific wireless system hardware component from the parts list library using pull-down menus and displayed dialog windows. The selection criteria for a particular component is wireless system design dependent, but generally involves the desirability of a component based upon its electrical characteristics and potential effect on wireless system performance, material cost, and/or installation cost. The present invention enables the designer to narrow the focus of component selection to only those devices contained within the parts list library that have the desired characteristics. For example, the design engineer may choose to design a wireless system using components from a specific manufacturer or set of manufacturers that have a desirable material cost and/or electrical characteristics. In doing so, only those devices that meet the requested criteria are displayed for selection from dialog windows in the present invention.

In certain instances, the operating frequency of a wireless communication device may define the electrical characteristics of the device. For example, depending on the frequency of the radio signal passing through an amplifier, the amplifier could have a varying amount of gain. Likewise, the radiating characteristics of antennas differ depending upon the frequency of the radio signal being broadcast. Coaxial cables, connectors, splitters, and other wireless communication system hardware components can also share this property of frequency dependent performance. To accommodate this, the parts list library from which the wireless communication system components are drawn may contain frequency specific information for each component. For example, an amplifier may have its gain specified for both 800 megahertz and 1900 megahertz. If this information is available within the parts list library for a component, the present invention automatically utilizes the frequency varying performance characteristics of the wireless hardware components within the performance prediction calculations as described below. The frequency of operation, in this case, is obtained from the transmitting source that is providing the radio signal to the wireless hardware component. For example, the base station or repeater to which the wireless hardware component is attached will have a range of frequencies or channels that it operates upon. In this case, the frequency of operation of the repeater or base station determines the frequency of the radio signal input into the wireless hardware component, and the frequency of the radio signal is in turn used to determine the operating characteristics of the component.

In addition to frequency dependent characteristics, many wireless communication devices have limitations in the manner in which they may be connected within an antenna system. Certain wireless communication hardware components are incompatible with other components and may not be connected together. For example, a fiber optic cable may not attach directly to a coaxial cable. Instead, a fiber optic cable would first connect to an optical-to-radio frequency converter device, which converts the data stream from optical into a radio signal. The coaxial cable would then connect to the output port on the optical-to-radio frequency converter. In the preferred embodiment of this invention, such connectivity restrictions are specified within the parts list library. Thus, the system automatically utilizes the information to prevent the designer from interconnecting incompatible components. If the designer attempts to interconnect two incompatible components, the present invention provides appropriate warning messages to notify the designer of the error.

Practicing communication network engineers spend tremendous amounts of time in the design and deployment phase trying to configure proper connections between communication components, such as coaxial cables, optical cables, adapters, antennas, routers, twisted pair cables, leaky feeder antennas, base stations, base station controllers, amplifiers, attenuators, connector splitters, antenna systems, repeaters, switches, wireless access points, cable boxes, signal splicers, transducers, couplers, splitters, convertors, firewalls, power distribution lines, hubs, and other communication components that are known and understood by

network engineers working in the cable, optical, wireless, networking and telephone industries. Often, various manufacturers make different brands of equipment, that are designed for particular frequency bands, mounting conditions, temperature conditions, and connector types. For example, radio frequency (RF) components often have N-connectors or SMA connectors which may not be interconnected without a proper adapter, and cables must have the proper type of connector in order to properly interconnect with other components. Similar connector types and sizes of connectors and cables exist for various makes and models of optical fiber cables, baseband twisted pair and CAT-3 and CAT-5 cables, radio frequency connectors and cables, and all other components listed above. Furthermore, network designers are often concerned about specific cost limitations, not just of a single device, but a connection of components, and often the entire system design. What's more, designers must avoid the improper mismatch of physical attributes, such as the improper connection of a very heavy component (say a switch box or a power amplifier) to a lightweight mounting fixture or a lightweight cable (say RG-58/u) that is unable to support the weight, temperature, or windload, for example. Also, particular network installations may be required in environments that have small size, low temperature, low or unusual power, or asthetic requirements, or other particular requirements that take into account the physical attributes of the components within the network design. One skilled in the art of design and deployment of communication networks is aware of other examples as taught here that typically arise in practical network design and deployment.

In addition, engineers and technicians often have particular brands or makes of products that they are required or wish to use in all of their designs. For example, their employer may insist that only certain brands be used for all deployment and design. Or, specific model numbers or series of part numbers may be required in a design. The specification and proper matching of brands or part numbers for the design of a network, which we term "brand choice", is important for desired results in many practical settings. Furthemore, components within a communications network must have compatable power connections (e.g., an RF distribution system would want to have active components that all use the same DC voltage, so that multiple power distribution lines would not have to be run), and components must be properly matched in size, weight, mounting configuration, impedance, and color. Also, designers must be sure that when they create a network design, components which they specify must have comparable maintenance requirements. For example, a designer should not create a network that requires some components to have constant maintenance, whereas others require only infrequent inspection and tuning (a mismatch in maintenance requirements).

On an even broader scale, it is helpful to have a simple checking method for making sure that components are properly designed to match the gross physical media of the various components. Some network components use and transfer or process optical frequencies (lightwaves), while others use radio frequency (RF), such as millimeter, UHF, VHF, or microwave signals, or baseband signals (VHF and below). Telephone cable, 10 baseT, twisted pair or CAT-5 type signaling is typically baseband, for example. Components which are modeled in the present invention can take in optical signals and transform them into RF or baseband signals. Similarly, some components take in RF signals and convert them to optical signals. In the design and deployment of a network, it is vital that optical cables be connected directly to optical sources, as opposed to RF or baseband signal sources. Otherwise, a network will not work. Other devices which take input signals that are at RF and produce output signals that are at optical frequencies exist. In addition, components that convert or transduce baseband-to-optical, or any other of a number of combinations of these various gross frequency bands. Physical media, which also may be called modality, may include the cables used in the network design, or may actually describe the processing components that receive and transmit at the different gross frequencies.

Components may not have compatible frequency ranges of operation, so that one part is designed for 800–950 MHz while another is designed for 1900–2100 MHz (or 200 nm vs. 300 nm, etc.). Components might have incompatibilities at the level of specific connectors, so that a connector on one component could connect with specific connectors on a specific component, but not with other connectors. Components also may require the connection of other specific components directly to them, or the presence of specific other components in the antenna system, RF distribution system, and power supply distribution system, in order to function correctly. Conversely, components may not allow the presence of specific other components, or of components from some manufacturers, to be connected directly to them, or even to be present anywhere in the design.

All of the above network design considerations are important for a designer or installer. Also, all of the individual connectors on each component within a network, as well as each frequency or gross frequency band used by each component and each connector on each component, needs to be properly tracked and must all be used and properly terminated for an effective network.

The above issues are all addressed in the present invention. Failure to meet any of the above desired criteria can be considered to be a "fault", wherein a fault can be detected automatically by the present invention in the design or deployment phase. Thus, desired cost, proper connectivity, proper matching of physical attributes, and proper connection of brands, part numbers, or manufacturers, can be readily detected and properly implemented with ease. Other faults, which follow the same logic as described above would fall within the scope of ths invention. When proper criteria are met, a fault will not be indicated, and the components within the design are used for computation of predictions of network performance. Also, the predictions of performance in a proper design may be compared directly to other designs within the same environment, as well as with actual measured field data.

Similarly, many wireless communication devices have limitations on the signal power that may be input into them. For example, an amplifier may only function properly if the input signal to the amplifier does not exceed a certain level of power. In the present invention, the power of a signal supplied to a wireless hardware component is determined to be the output power of the radio signal leaving the device to which wireless hardware component is attached within the antenna system. Typically, wireless communication system hardware components have gains and/or losses such that when a radio signal passes through a component, the radio signal is either amplified or attenuated depending on the operating characteristics of the component and the frequency of the radio signal. For example, referring to FIG. 4, one of the omnidirectional antennas **403***a* is attached to a coaxial cable **402**, which in turn is attached to a transmitter **107** via a splitter **401**. If the transmitter **107** is transmitting with a signal power of 10 dBm, and the total loss of the

splitter **401** is 4 dB, the input signal power into the coaxial cable **402** is 6 dBm (the signal power of the transmitter minus the total loss of the splitter). Similarly, if the total loss of the cable **402** is 2 dB, the input signal power into the antenna **403***a* is 4 dBm. In the preferred embodiment of the invention, the parts list library contains information regarding the restriction of input signal power into a component. This allows the system of the present invention to notify the user of the fault in the design via displayed computer dialog boxes if, given the present configuration of the antenna system that has been visually configured and interconnected in the 3-D environmental model, that the input signal power into any of the wireless communication system hardware components exceeds the limits specified in the parts list library. This immediate feedback is invaluable to the designer and provides instant recognition of potential problems in the configuration of the antenna system.

Similarly, many cable components used in wireless communication systems have limitations on the total length of any single segment of the cable. For example, a single segment of a specific fiber optic cable may not have a length exceeding 500 feet in order to maintain the integrity of the signal passing through it. In the preferred embodiment, the parts list library will contain such length limitations specified for cabling components. Therefore, if the designer visually configures a segment of cabling within a wireless communication system such that the total length of the segment exceeds the maximum cable length specified for the cable component within the parts list library, a warning message concerning this fault in the design is displayed to the designer via computer generated dialog boxes stating the error. The total length of the cable segment is determined from the manner in which the designer has positioned the cable within the 3-D environmental database. For example, referring again to FIG. **4**, the length of the coaxial cables **402** in the figure is determined on the basis of their physical placement and orientation within the 3-D environmental model. This immediate feedback provides invaluable information to a wireless system designer as it prevents potential errors in the wireless communication system design. The maximum length restriction applies to all varieties of cabling components, such as coaxial cables, fiber optic cables, leaky feeder antennas, and any other type of wireless hardware cable.

Other limitations of a component may be imposed. The component may need to be within a certain distance from a base station, regardless of intervening components. A component may need to be a certain height above ground level, within a certain distance from a wall (internal or external) or from a high-voltage power supply source, or placed in a room of sufficient size. A component may be illegal for use in a given location, or unavailable from the manufacturer from a given ordering location. A component may be too large to fit through existing apertures providing access to an indoor location as modeled in the 3-D environment database above. A component may be too heavy for a floor, or too lightweight for an unattached position. A component may be the wrong size, color, or shape. A component may be unsuitable for environmental conditions at a given indoor or outdoor location. Components made by specific manufacturers may be unsuitable. Components exceeding a percomponent price limit may be unsuitable for a given design; such limits may be set for a given type of component e.g. amplifier, antenna, or cable, or may be set for any type of component. One skilled in the art could formulate many other obvious attributes that could also be checked for faults in a design, in the same manner.

A component may be marginally compatible with a given antenna system and RF distribution system for a given site. Manufacturer-specified warnings, maintained with other component characteristics in the component library, could be delivered appropriately for these situations. For example, a manufacturer may specify that a given component may be used at a given power level and perform properly, but that the engineer should be warned that the component will have a reduced operational lifetime, or may perform in a suboptimal manner, or cause damage to other connected parts, if used at the current input signal strength level. One skilled in the art would understand that this extends to other fault warnings about other marginally suitable components.

The present invention stores these fault warnings and the relevant conditions under which the warnings apply, in the parts list library, and automatically compares the conditions in which a component is placed in an antenna system and RF distribution system in a 3-D model of a wireless network site, and if the conditions match, displays a fault warning dialog window (not shown) to the user containing the manufacturer's warning, which must be dismissed and/or printed before the engineer is allowed to proceed with the design.

In the present invention, a cost limitation may be imposed on a given design, such that when the engineer places a component which would cause the total cost of the installation, or a portion of the installation (which is tracked in real time as indicated above) to exceed the limit, a fault warning is given. At this point, components which are relatively expensive, or inexpensive components appearing repeatedly in the design, might be identified automatically by the system as candidates for replacement for cheaper parts.

FIG. **19** shows a high level schematic of one mechanism which may be used to provide the design engineer with information on system performance and cost information. In block **1800**, he selects components which will be used in the computerized model of the physical environment in which the communications network is or will be installed. There will be a plurality of different types of components which can be selected (e.g., splitters, antennas, transmitters, base stations, cables, etc.), and there will be a plurality of models of the types of components selected (e.g., various types of fiber optic cables, coaxial cables, antennas, etc.). The components will have various attributes **1802** (e.g., type of signal carried (i.e., optical or radiowave), maximum propagation length (for cables), etc.), frequency characteristics **1804** (e.g., electrical properties of a component at two or more frequencies, etc.), and cost **1806** information associated with one or more components which are selected in decision block **1800**. The selected components will then be displayed on the computerized representation of the physical environment in which the communications system is or will be installed in block **1808**. The system will automatically determine, based on the attributes **1802**, whether the components selected can properly work together as intended by the designer or whether the components will satisfy all of the demands required of them in the communications system designed by the designer or any other error which may be present in the communications network at decision point **1810**. If the communications network will not perform properly, the designer will be notified of the fault(s) in the design by a display on the screen, audible warning, or other effective means at block **1812**. This will allow the designer to go back and select more suitable components. If there are no faults in the design proposed by the designer, one or more prediction models will be run at block **1814**, and the results

of these calculations will be displayed to the designer at block **1816**. If changes in frequency parameters are to be considered in the prediction models, this can be done at block **1818**. If desired, the cost of the componentry used in the communications network designed by the designer can be provided in a bill of materials at **1820**.

In addition, in the preferred embodiment the parts list library contains specifications for compound components, hereafter referred to as "component kits." A component kit is a predefined group of select individual wireless communication components which may or may not be partially or wholly interconnected and arranged. Component kits are specified separate from a 3-D environmental model and are not related to the physical layout of a facility. For example, a component kit could consist of a specific splitter connected with a specific cable, which in turn is connected with a specific antenna. The component kit does not define where in the 3-D environmental model the splitter, cable, and antenna are positioned, but simply identifies that they are connected or assembled together. The designer may then select the component kit itself in exactly the same manner as any other individual hardware component and position the complete kit within the 3-D environmental model. Thus, by selecting the kit and positioning it within the 3-D environmental model, the designer has automatically selected and positioned the splitter, cable, and antenna.

An important and novel capability of the present invention is the ability to provide communication network performance predictions that use the component kits, and to allow such predictions to be compared with measured network data. In practice, actual communication networks may be configured using system components which are configured in a specific manner, and this specific physical and electrical representation may be done approximately or completely in its entirety by a component kit. Component kits also contain much more detailed information of each component or subsystem within the kit, such as physical media specifications for proper gross frequency interconnection, physical attributes, cost, depreciation and maintenance schedule information, so that proper interconnections within a kit, and from one or more kits to another kit, or from one or more kits to a network, may be made without a "fault", as described herein. Measurements made from actual systems comprised of components that are modeled either exactly or approximately in a component kit within the present invention may be displayed, stored, and compared directly to predictions made by systems designed with the component kit.

Referring to FIG. **20**, there is shown a representation of the component kit computer editing window in the preferred embodiment of the invention. In FIG. **20**, a component kit named "Component Kit #1" **1001** is shown. The component kit represents five individual components that are interconnected in a certain fashion. A coaxial cable **1002** is connected with a splitter **1003**. One output connector of the splitter connects to an antenna **1004**, while the other output connects to a leaky feeder antenna **1005**. The leaky feeder antenna then terminates **1006**. The computer editor window **1007** graphically portrays the interconnection of the various components, and enables the designer to add or remove components to the component kit. Once created, the component kit **1001** can be selected and positioned within the 3-D environmental model just as any individual component. For example, FIG. **21** shows each of the components **1002–1006** of component kit **1001** positioned in one room of a three dimensional floor plan. The design engineer can then connect other components in the communications network,

but also may select other groups of components or "component kits" for use in the facility defined by the three dimensional floor plan (or multistory facility or campus wide communications network). This enables the designer to quickly place multiple components in the 3-D environmental model by enabling the multiple components to be selected as placed as a single component.

Once a desired component is selected by pointing and clicking with a mouse or other input device (components and component kits may be imported, exported, and exchanged electronically and textually between users in the preferred embodiment of the invention), the design engineer may position the component within the three dimension environmental database. This process involves the design engineer using the mouse or other input device to visually identify the desired location for the component by clicking (or otherwise identifying) positions within the 3-D environmental database. For example, an antenna component could be placed within a specific room of a building, atop a flag pole on the side of a building, in the center of a park, or any other location deemed reasonable by the designer. In similar fashion, hardware components that span distances (e.g. coaxial cable, fiber optic cable, leaky feeder antenna, or any component having substantial length) are selected and positioned within the 3-D environment by clicking with the mouse or other input device to identify the vertices (or end points) of the component where each pair of vertices are connected by a time segment representing a portion of cable. Thus, while certain components, such as point antennas or splitters, for example, require only a single point in the 3-D environment to identify placement in the wireless communication system, other components such as distribution cables or distribution antennas require the identification of multiple points joined by line segments to identify placement. In the present invention, unique graphic symbols are utilized to represent each wireless system component and overlaid onto the three-dimensional environmental database enabling the designer to visualize the wireless communication system as it would exist in the physical world. As an example of the graphical display and shown only in two dimensions for convenience, FIG. **4** displays a base station **107** connected via two coaxial cables **402** to two indoor point antennas **403***a* and **403***b*.

The present embodiment of the invention provides and links information relating to wireless system component dependence. Such dependencies may include but are not limited to impedance matching of adjoining components, maximum run length, proper termination, or some other fault, as described herein. Certain components in the parts list library may require pre-existing components to have been positioned within the 3-D environmental database before they themselves may be selected and added to the wireless system. For example, a splitter or other device designed to interconnect two or more independent components may require that an existing component be present in the three dimensional database for the splitter to be connected with. In the previous embodiment of the invention, if the designer chooses to place a hardware component within the 3-D environmental database, and the desired component is dependent upon some other device currently placed in the 3-D database, the designer is prompted through a selection window to identify the dependent component and the selected component is positioned accordingly. In the previous example of the splitter component, if the designer chooses to connect the splitter onto the end of an existing cable component by identifying the cable component with the mouse or other input device, the position of the splitter

within the three-dimensional database is automatically assigned to be the end of the identified cable. In this way the invention helps prevent the user from creating faulty designs. Wireless system components that do not have such dependencies (e.g., base station transceivers) may be freely positioned anywhere within the 3-D environmental database that is deemed suitable by the designer. As this description is specific to one particular implementation, one skilled in the art could see how different implementations could be developed and practiced within the scope of this invention.

In the preferred embodiment of the invention, if the wireless communication hardware components have information specified within the parts list library detailing restrictions on, for example, maximum input signal power, maximum length, or connectivity restrictions, the present invention will notify the designer immediately if any of these restrictions or limitations are exceeded during the course of the design. This notification of a potential fault occurs via computer generated dialog boxes containing textual warning messages detailing the restriction or limitation being exceeded with the present configuration of the wireless communication system within the 3-D environmental model.

Using the preferred embodiment of the invention, a designer can model and represent, visually as well as mathematically, complex wireless communication systems involving any number of individual hardware components selected from the parts list library, interconnected with and linked to one another to form complete antenna systems. As each component has associated characteristics regarding electrical properties (e.g. gain, noise figure, attenuation) and cost, the addition, removal, or change of any component directly impacts both the performance of the wireless system and the overall system cost. With the preferred embodiment of the invention, this information is updated in real-time as the designer makes changes to the wireless system. If a wireless communication system includes a specific hardware component, the present invention retrieves the associated electromechanical characteristics and other pertinent information from the parts list library entry that has been specified for the component. This information is stored in a database and is then used to quantify the effect that the component has on various aspects of wireless system design parameters or performance. For example, if the parts list library information for a specific cable indicates that the attenuation loss of the cable is 3.5 dB per 100 meters, and the designer has added a 200 meter segment of the cable to the wireless communication system, the present invention combines the information regarding the placement and length of the cable in the 3-D environmental database with the attenuation loss information from the parts list library to determine a total attenuation loss of 7 dB for the cable. Furthermore, the noise figure and other related qualities of the cable is also computed based upon well known communication theory. If the designer then adds an amplifier to the wireless system and connects it onto the end of the cable as described above, the invention retrieves information regarding the amplifier from the parts list library to determine overall gain of the wireless distribution system. If, for instance, the selected amplifier has an associated gain of 10 dB and some specified noise figure, the present invention combines the characteristics of the interconnected cable and amplifier to determine a total gain of 3 dB for the combined components, and a new system noise figure. If the designer edits or alters component information in the parts list library, this is automatically reflected in the wireless system performance prediction. For example, if the amplifier in the example above has the gain associated with it edited in the parts list library and changed from 10 dB to 15 dB, the combined system characteristics, which may include but are not limited to system gain and system noise figure, of the cable and amplifier from the example are automatically recalculated, resulting in an overall gain of 8 dB instead of 3 dB. Similarly if the cable is repositioned such that its overall length is altered or replaced with a different component from the parts list library, the effect of doing so is automatically recalculated an reflected in all future operations.

As mentioned previously, the Parts List Library preferably contains information regarding the frequency dependent nature of a wireless system component, the operating characteristics of the component utilized during the calculation of gains, losses, noise figure, or any other qualities that utilize the frequency of the input signal into the component to determine the specific set of operating characteristics for the component. If the component does not have a set of parameters defined for the desired operating frequency, the present invention searches for and uses the set of operating parameters specified for the frequency closest to the actual frequency of the input signal. This is a very powerful feature of the present invention as it enables a designer to select components for use in a wireless communication system without the need to worry about the operating parameters of the component relative to the operating frequency of the wireless communication system. The present invention automatically uses the best set of frequency dependent parameters specified for each wireless hardware component based on the frequency of the input signal to the component.

The Parts List Library, or component library, of the present invention also contains information regarding operating characteristics of a component which depend on some combination of the frequency of the input signal to the component, the connector on the component to which the input is applied or through which output is passed, and the direction of the signal, i.e., forward link from the base station to the mobile receiver or reverse link back to the base station from the mobile receiver. The preferred embodiment specifies a coupling loss that applies to a particular component, for a particular frequency range and modality, for a particular connector on the component, for a particular directionality of signal (i.e., forward link or reverse link). A different coupling loss is specified explicitly (or may be derived automatically) for each combination of connector, supported frequency band (of which a given component may have many), and directionality. These values are preferably applied automatically in real time to the aforementioned system performance predictions, according to the active frequency of the signal arriving at and/or leaving a component, the connector on which the modeled signal arrives at and/or leaves the component, and whether the forward link or reverse link performance is being evaluated. One skilled in the art could implement additional specifications dependent on combinations of the frequency, connector, directionality, or other aspects of the signal applied to a component.

Although the given example is in terms of simple gains and losses of the individual wireless components, one skilled in the art could apply this same method to any other electrical, electromechanical financial, aesthetic or other quality associated with components in the parts list library and the overall system in a similar fashion.

A preferred Parts List Library is designed to be generic and applicable to any type of wireless communication

system component or wireless communication system design methodology. There are eight basic categories of components in the preferred parts list library utilized in the preferred embodiment, although more categories could be added, as desired:

1. Amplifiers/Attenuators—generally speaking, devices that either boost or decrease the strength of radio wave signals;
2. Connectors/Splitters—generally speaking, devices that connect one or more components to one or more additional components;
3. Cables—various types of cabling (e.g., fiber optic cable, coaxial cable, twisted pair cable, etc);
4. Manufacturer-Specified Point Antennas—any antenna that is manufactured and whose manufacturer has supplied information with regard to the radiation pattern of the antenna. The radiation pattern of an antenna describes the manner in which radio signals are radiated by the antenna. Antenna manufacturers supply radiation pattern information regarding their antennas so that wireless system designers can maximize the effectiveness of antenna deployments;
5. Generic Point Antennas—any generic or idealistic antenna (that is, an antenna that may not be physically realizable or has a generic radiation pattern);
6. Leaky Feeder Cabling/Antennas—a type of antenna that takes the form of a specialized coaxial cable;
7. Base Station/Repeater—the controlling portion of the wireless communication system. The base station manages all communication taking place in the wireless network;
8. Component kit-one or more individual components interconnected or grouped interconnected together to form a compound component (this preferably being done within the discretion of the design engineer by selecting amongst all or some of the components in the Parts List Library to define one or more component kits made of selected components). The component kit is referenced as a single hardware component and enables the designer to quickly add and manipulate multiple wireless hardware components. It preferably has no directly assigned electromechanical properties defined in the Parts List Library; however, the individual hardware components contained within the component kit retain all electromechanical properties assigned to them within the Parts List Library; and
9. Other—Any component that does not belong in one of the above categories.

Each component has a variety of associated values. These include, but are not limited to:

Manufacturer Name;

Manufacturer Part Number;

User-supplied Description;

Frequency range at which part has been tested;

Attenuation/Amplification;

Number of Connections;

Physical Cost (material cost of component);

Installation Cost;

Antenna Radiation Pattern;

Maximum input signal power;

Maximum length (for cables);

Modality of component type (e.g., optical, radio signal, etc.)

Note that many or all of the associated values listed above could vary depending on the frequency of the input signal to the component. They may also depend on the combination of input signal frequency, connector on the component to which the signal is applied or via which the signal exits the component, and whether the signal is a forward link signal originating at the base station, or reverse link signal originating from a user of the system. The parts list library utilized in the preferred embodiment of the invention allows the amplification/attenuation, radiation pattern, and maximum input signal power to be identified for specific frequencies of frequency ranges for each wireless hardware component. The coupling loss varies by frequency, connector, and direction of signal (forward or reverse link), in the preferred embodiment.

Base stations and repeater components have a number of additional parameters associated with them, including, but not limited to:

Technology/Air Interface—identifies the wireless technology employed by the base station (e.g., AMPS ("analog cellular"), IS-136 ("digital cellular"), IEEE 802.11 ("wireless LAN"), etc.);

Frequency/Channel Assignments-identifies the radio frequencies/channels this base station can utilize; and

Transmit Power—the amount of power the base station is broadcasting.

An excerpt from the preferred embodiment of a parts list is shown below.


```
<ComponentSpec>
    <databaseKey>5110</databaseKey>
    <name><![CDATA(Ultraflexible Series Cable]]></name>
    <type>CABLE</type>
    <manufacturer><![CDATA[Bob's Cables and
        Connectors, Inc.]]></manufacturer>
    <partNumber><![CDATA[Model 21-A]]></partNumber>
    <purchaseCost>0</purchaseCost>
    <installationCost>0</installationCost>
    <maximumLength>none</maximumLength>
    <fileDescriptor><![CDATA[N/A]]></fileDescriptor>
    <otherInfo><![CDATA[N/A]]></otherInfo>
    <connectorCount>2</connectorCount>
    <bandList>
        <BAND>
            <modality>R</modality>
            <minFreq>4e+008</minFreq>
            <maxFreq>4e+008</maxFreq>
          <inputSignalMaxFwd>none</inputSignalMaxFwd>
          <inputSignalMaxRev>none</inputSignalMaxRev>
        <outputSignalMaxFwd>none</outputSignalMaxFwd>
        <outputSignalMaxRev>none</outputSignalMaxRev>
            <insertionLoss>7.42</insertionLoss>
            <associatedConnector>
                <number>0</number>
                <couplingLossFwd>0</couplingLossFwd>
                <couplingLossRev>0</couplingLossRev>
            </associatedConnector>
            <associatedConnector>
                <number>1</number>
                <couplingLossFwd>0</couplingLossFwd>
                <couplingLossRev>0</couplingLossRev>
            </associatedConnector>
        </BAND>
        <BAND>
            <modality>R</modality>
            <minFreq>4.5e+008</minFreq>
            <maxFreq>4.5e+008</maxFreq>
          <inputSignalMaxFwd>none</inputSignalMaxFwd>
          <inputSignalMaxRev>none</inputSignalMaxRev>
        <outputSignalMaxFwd>none</outputSignalMaxFwd>
        <outputSignalMaxRev>none</outputSignalMaxRev>
            <insertionLoss>7.87</insertionLoss>
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-continued


```
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            </associatedConnector>
        </BAND>
    </bandList>
</ComponentSpec>
```


This excerpt from the parts list of the present invention is the complete specification of a single component. The excerpt is in XML format, and each element of the specification is labeled with XML tags. The <ComponentSpec> tag begins the component, the <databaseKey> tag indicates the internal database key used to index the part, and the </databaseKey> ends the value for the internal database key. Similarly, the specifications include the manufacturer identified by <manufacturer>, the part name identified by <name>, and so on. There is also a list of frequency bands, marked off by a <bandList> tag. Each band, demarcated by a <BAND> tag, contains specifications which apply only when the signal applied to the component is closest to the particular band. For a band, the modality (e.g. optical, RF, baseband, CAT-5) is indicated with a <modality> tag, and symbolized by 'R' for RF, 'O' for optical, etc. The minimum and maximum frequency that bound the band are marked by <minFreq> and <maxFreq> tags; the signal maxima for input and output, forward and reverse link, respectively, for the band are also defined, as is the insertion loss for the band. Finally, a list of connectors supported by the band in question appears, marked by an <associatedConnector> tag. Each set of specifications for an associated connector include the connector number as an identifier, and a separate coupling loss for the forward link and for the reverse link, identified by the <connectorNumber>, <couplingLossFwd>, and <couplingLossRev> tags.

Thus the present invention defines specifications dependent on the frequency alone; dependent on the frequency and the component's connector; and dependent on the frequency, the connector, and the link direction, whether forward or reverse.

The parts list can be easily modified by a design engineer as new components are placed on the market, removed from the market or re-priced. The ability to maintain a unique equipment list for each drawing enables the designer to carry out rapid design analyses to compare and contrast the performance and cost of different vendor components. The impact of utilizing a specific component in terms of both cost and wireless communication system performance can be seen immediately using the present invention. Information that can be tracked with the bill of materials includes the manufacturer and part number, physical and installation cost, RF loss characteristics, connections, and the frequencies for which the component is valid. In addition, a rich set of customization features is utilized to enable the designer to tailor the parts list library to suit the needs of the target application. Moreover, as components with associated length data, such as cables or leaky feeder antennas, are created, stretched, moved or modified, their associated costs and impact on wireless system performance are automatically updated in the bill of materials to account for the change in length. Furthermore, the parts list is stored as an integral part of the drawing database, allowing the user to recall and archive a system design and all of its particulars. In addition, the wireless communication system performance may be recalculated immediately, using either a standard link budget equation, noise figure equation, or some other metric such as bit error rate or network throughput. This recalculation uses the specific, perhaps frequency specific electrical specifications of each component in the system, which are also stored in the bill of materials.

Referring again to the drawings, and more particularly to FIG. **16**, there is shown an example of a bill of materials summary for a drawing. A description of the base station "MACROCELL" **1610** is shown to identify the antenna system for which the summary is shown. The first component **1611** is a PCN Panel **1710**-1990 92 Deg 9.00 dB Gain point antenna manufactured by Allen Telecom. One should note that the component cost **1612**, sub-total cost **1613** and total system cost **1614** is $0.00. This shows that the designer has not yet updated the parts list library with current costs. When the list has been updated, the summary will automatically show component costs as well as sub-totals and totals for all base stations and components in the drawing.

FIG. **17** show a bill of materials where costs have been entered into the parts list database. Another component **1720** has been added to the "MACROCELL" base station, also. The costs of each component **1612*a*** and **1721** are now shown. Sub-total **1613*a*** and Total costs **1614*a*** are also shown.

Referring now to FIG. **18**, the general method of the invention is shown. As previously described, first the designer must create a database defining the desired environment in function block **180**. A preferred method is disclosed in the co-pending application Ser. No. 09/318,841. A database of components is then developed in function block **181**. In the case of wireless communication networks, a preferred method is described above. The creation of these components will automatically generate a parts list categorized by base station and antenna system. A bill of materials may be displayed at any time in function block **182**.

In order to optimize the design of the wireless communications system and ensure adequate antenna coverage, the designer runs a series of prediction models and optimization techniques in function block **183**. A preferred method for running predictions is described above. This method allows the designer to see, in real-time, changes in coverage, generally, and for specifically chosen watch points, as antennas are repositioned or reoriented. The designer may choose to add, delete or substitute components in function block **184** and then re-run the models again in function block **183**. Each time the designer makes a modification in the system to improve performance, the bill of materials is automatically

updated. The designer may run the prediction models in function block **183**, and determine if the wireless system, as designed, is adequate in terms of performance and cost. If not, the designer can choose to modify components using cost or component performance considerations. Performance parameters may be entered to enable the designer to choose substitute components from a list that contains only those components that would not degrade the performance of the overall system. Note that in the preferred embodiment, the prediction or system performance models are recomputed upon user demand, but that it would be apparent to one skilled in the art to also have models recomputed instantly ("on-the-fly") as new components are added or subtracted from the bill of materials.

The integration of the bill of materials and component performance specifications is key to providing a quick and efficient method to design high performance wireless communication networks that are within budget. In addition to individual component physical and installation costs, a collection of components that may be interconnected or possibly used within a common network may also be specified. Such components from a component kit may be used in a design, and also may be considered for physical and installation cost. Moreover, within a bill of materials containing a list of network components, there may also be a tabulation, computation and storage of other important cost information for some of the components, such as cost depreciation values, or schedules for depreciation of particular components or groups of components. Such information may be available for only certain components within a network or within a parts list provided by a particular manufacturer. In addition, maintenance schedule information, which specifies the particular period or dates during which routine maintenance is required, may be included within the description of components within a bill of materials, to help the maintenance staff to properly maintain the designed network.

While the invention has been described in terms of its preferred embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the appended claims.

Having thus described our invention, what we claim as new and desire to secure by Letters Patent is as follows:

1. A method for designing or deploying a communications network, comprising the steps of:

providing a computerized model which represents a physical environment in which a communications network is or will be installed, said computerized model providing a display of at least a portion of said physical environment;

providing performance attributes for a plurality of system components which may be used in said physical environment, a number of said system components having associated with them frequency dependent characteristics;

selecting specific components from said plurality of system components for use in said computerized model;

representing said selected specific components in said display;

running prediction models using the computerized model and said performance attributes to predict performance characteristics of a communications network comprised of said selected specific components, said prediction models utilizing said frequency dependent characteristics in calculations which predict said performance characteristics of said communications network.

2. The method of claim **1** wherein said frequency dependent characteristics define electrical properties of said system components at at least two different frequencies.

3. The method of claim **1** further comprising the step of generating a bill of materials containing cost information for said selected specific components utilized in said communications network.

4. The method of claim **3** wherein said cost information comprises a maintenance schedule for selected specific components.

5. The method of claim **1** wherein said display is three dimensional.

6. The method of claim **1** wherein said system components allow converting between radio frequency and optical frequency.

7. The method of claim **1** wherein said system components allow converting between optical frequency and baseband frequency.

8. The method of claim **1** wherein said system components allow converting between radio frequency and baseband frequency.

9. The method of claim **1** further comprising the step of identifying errors in physical media connections for two or more specific components selected in said selecting step.

10. An apparatus for designing or deploying a communications network, comprising:

a means for providing

(I) a computerized model which represents a physical environment in which a communications network is or will be installed, said computerized model providing a display of at least a portion of said physical environment, and

(II) performance attributes for a plurality of system components which may be used in said physical environment, a number of said system components having associated with them frequency dependent characteristics;

a means for selecting specific components from said plurality of system components for use in said computerized model;

a means for representing said selected specific components in said display; and

a means for running prediction models using the computerized model and said performance attributes to predict performance characteristics of a communications network comprised of said selected specific components, said prediction models utilizing said frequency dependent characteristics in calculations which predict said performance characteristics of said communications network.

11. The apparatus of claim **10** further comprising a means for generating a bill of materials containing cost information for said selected specific components utilized in said communications network.

12. The apparatus of claim **11** wherein said cost information comprises a maintenance schedule for selected specific components.

13. The apparatus of claim **10** wherein said display is three dimensional.

14. The apparatus of claim **10** further comprising a means for identifying errors in physical media connections for two or more selected specific components.

* * * * *

EXHIBIT D

US006973622B1

(12) **United States Patent**
Rappaport et al.

(10) **Patent No.: US 6,973,622 B1**
(45) **Date of Patent: Dec. 6, 2005**

(54) **SYSTEM AND METHOD FOR DESIGN, TRACKING, MEASUREMENT, PREDICTION AND OPTIMIZATION OF DATA COMMUNICATION NETWORKS**

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(73) Assignee: **Wireless Valley Communications, Inc.**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 724 days.

(21) Appl. No.: **09/668,145**

(22) Filed: **Sep. 25, 2000**

(51) **Int. Cl.**[7] **G06F 3/00**; G06F 19/00; G06F 15/16

(52) **U.S. Cl.** **715/735**; 715/736; 703/21; 703/22; 709/221

(58) **Field of Search** 703/2, 3, 5, 21, 703/22; 455/33.1, 33.4, 564, 446; 345/133; 202/186; 715/735, 736, 734; 709/221, 222

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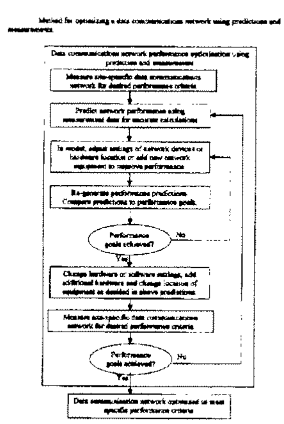
(74) *Attorney, Agent, or Firm*—Whitham, Curtis & Christofferson, PC

(57) **ABSTRACT**

A system and method for design, tracking, measurement, prediction and optimization of data communications networks includes a site specific model of the physical environment, and performs a wide variety of different calculations for predicting network performance using a combination of prediction modes and measurement data based on the components used in the communications networks, the physical environment, and radio propagation characteristics.

68 Claims, 6 Drawing Sheets



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Company Web Page "Agilent" www.agilent.com product name: Wizard, no date given.
Company Web Page "Camarco" www.edx.com product name: SignalPro, no date given.
Company Web Page "ComOpt" www.comopt.com product name: CellOpt AFP, no date given.
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Company Web Page "Marconi" www.marconi.com product name: PlaNET, no date given.
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Company Web Page "Schema" www.schema.com product name: Optimizer, no date given.
Company Web Page "ScoreBoard" www.scoreboard.com product name: ScoreBoard, no date given.

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Figure 1: Example transmission of data over a communications network

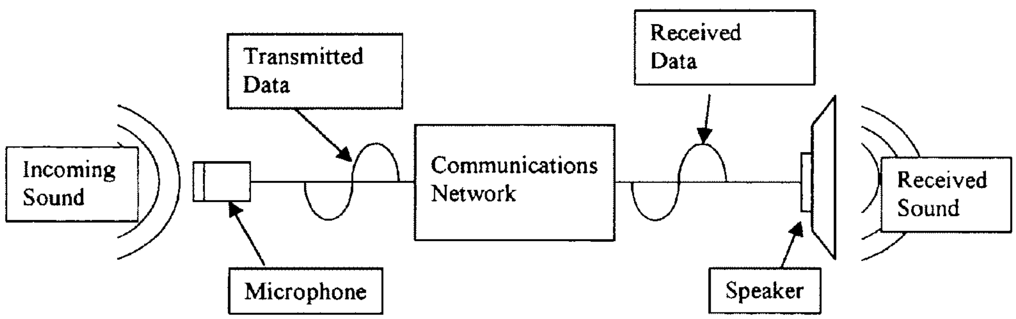


Figure 2: Creation of a digital signal from an analog signal

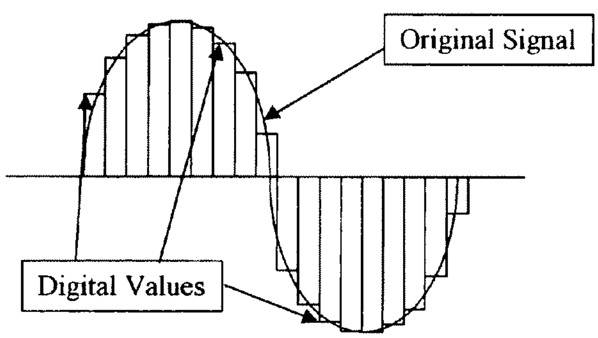


Figure 3: Illustration of the difference between bits, packets and frames.

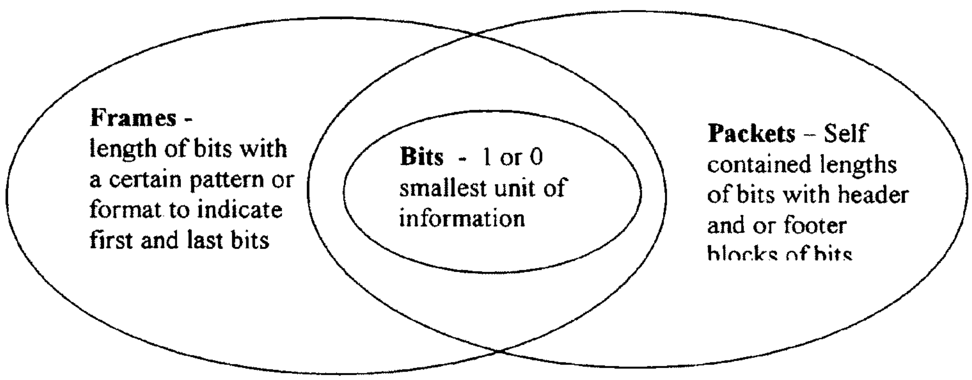


Figure 4: Illustration of the data displayed in each node of the Tree View of a data communications network.

- Name and type of network device
  - Specifications
    - Electrical, Optical, and Electromagnetic specific operating parameters
    - Software, Firmware and Hardware version numbers and settings
  - Physical connectors
    - Specifications and setting specific to each connector

Figure 5: Method for creating a 3-D site specific model of the environment

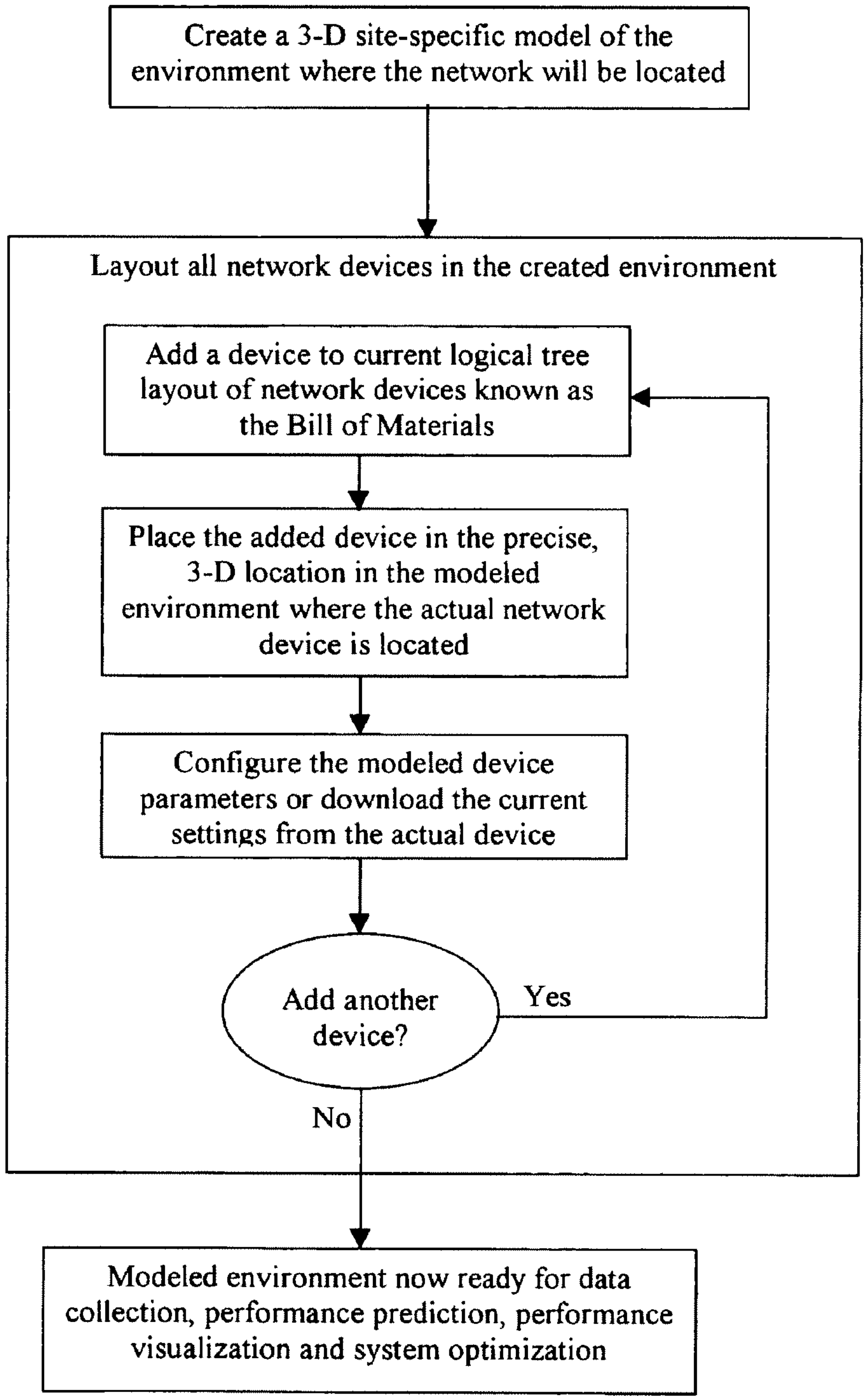


Figure 6: Method for optimizing a data communications network using predictions

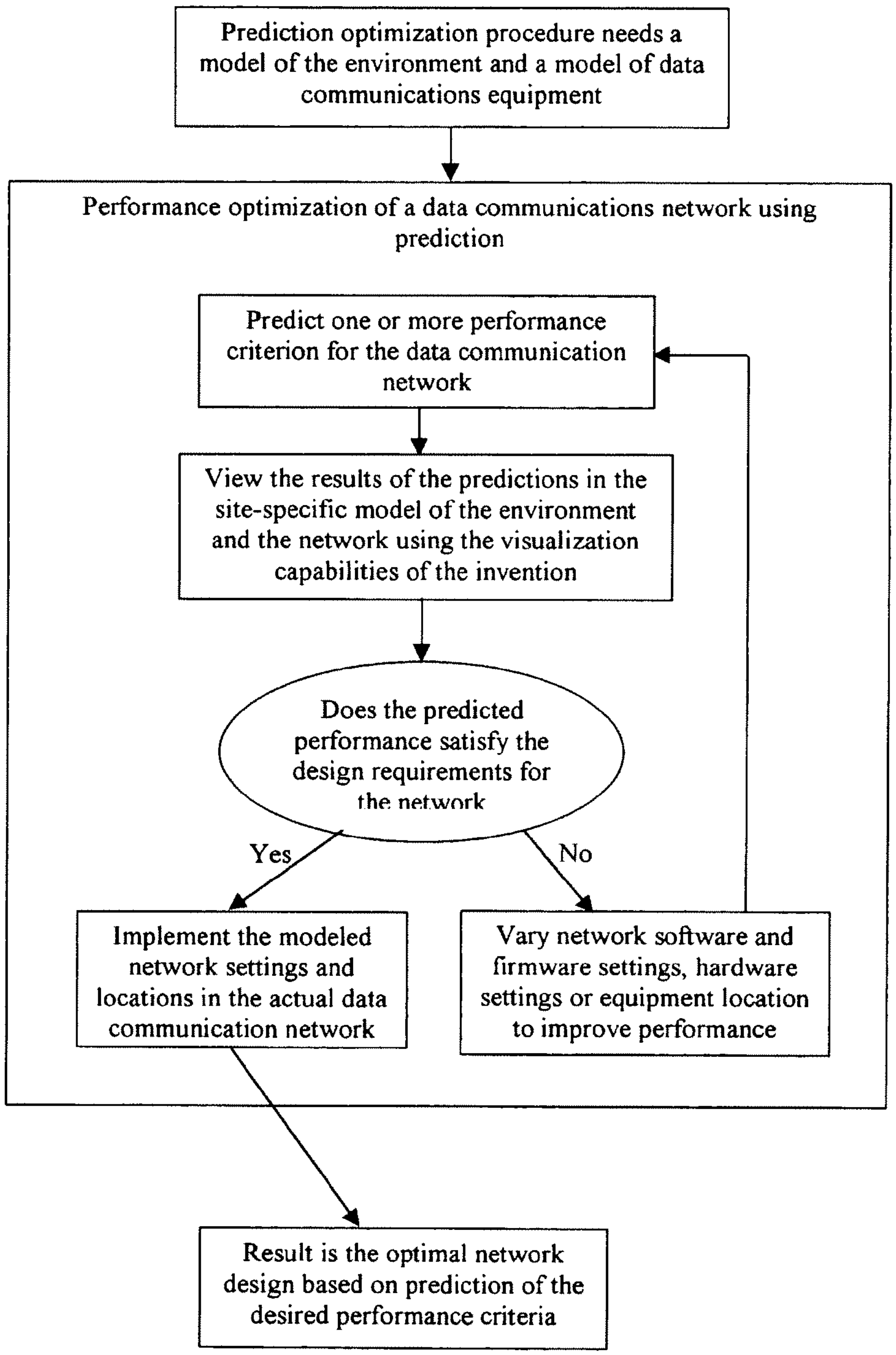


Figure 7: Method for optimizing a data communications network using measurements

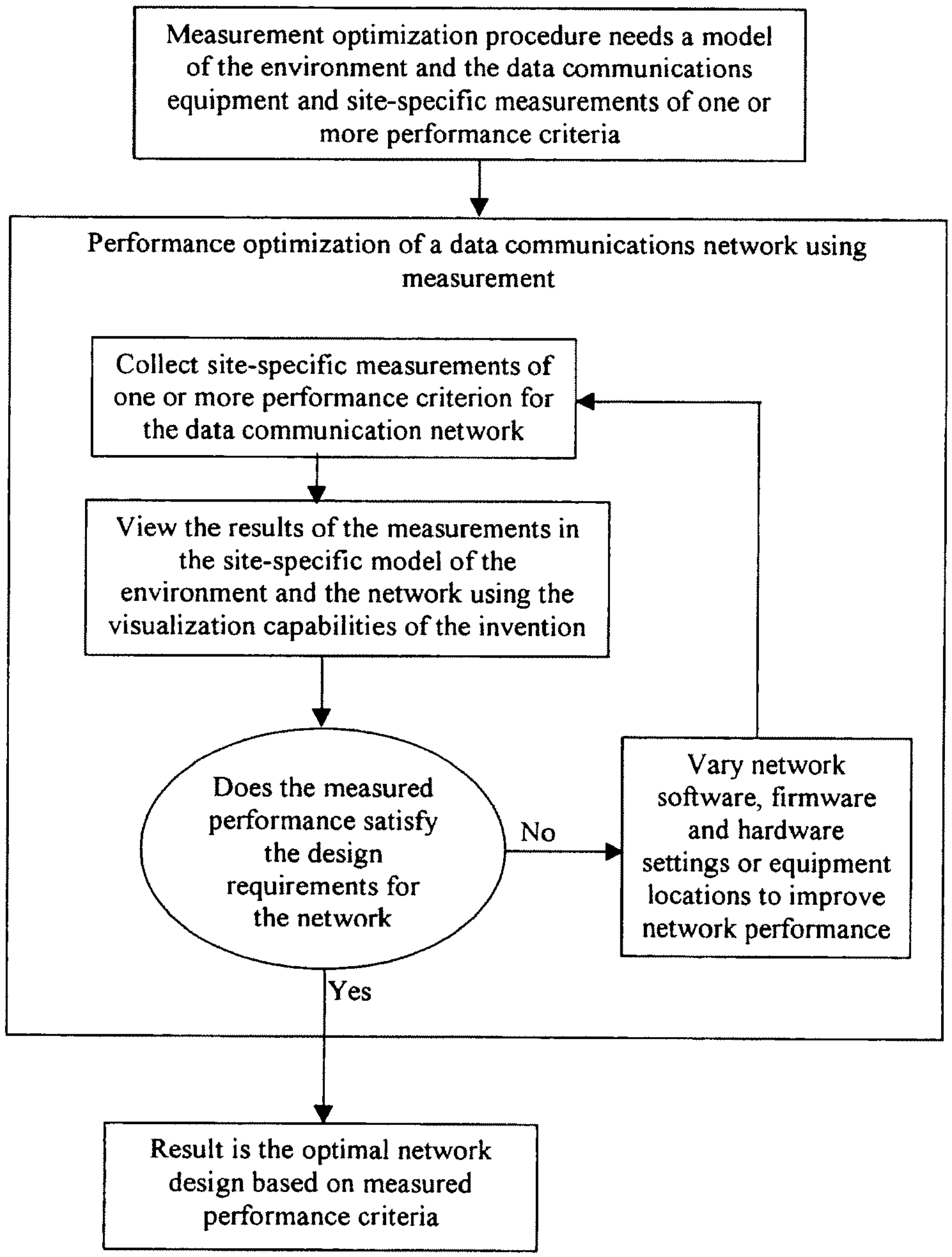
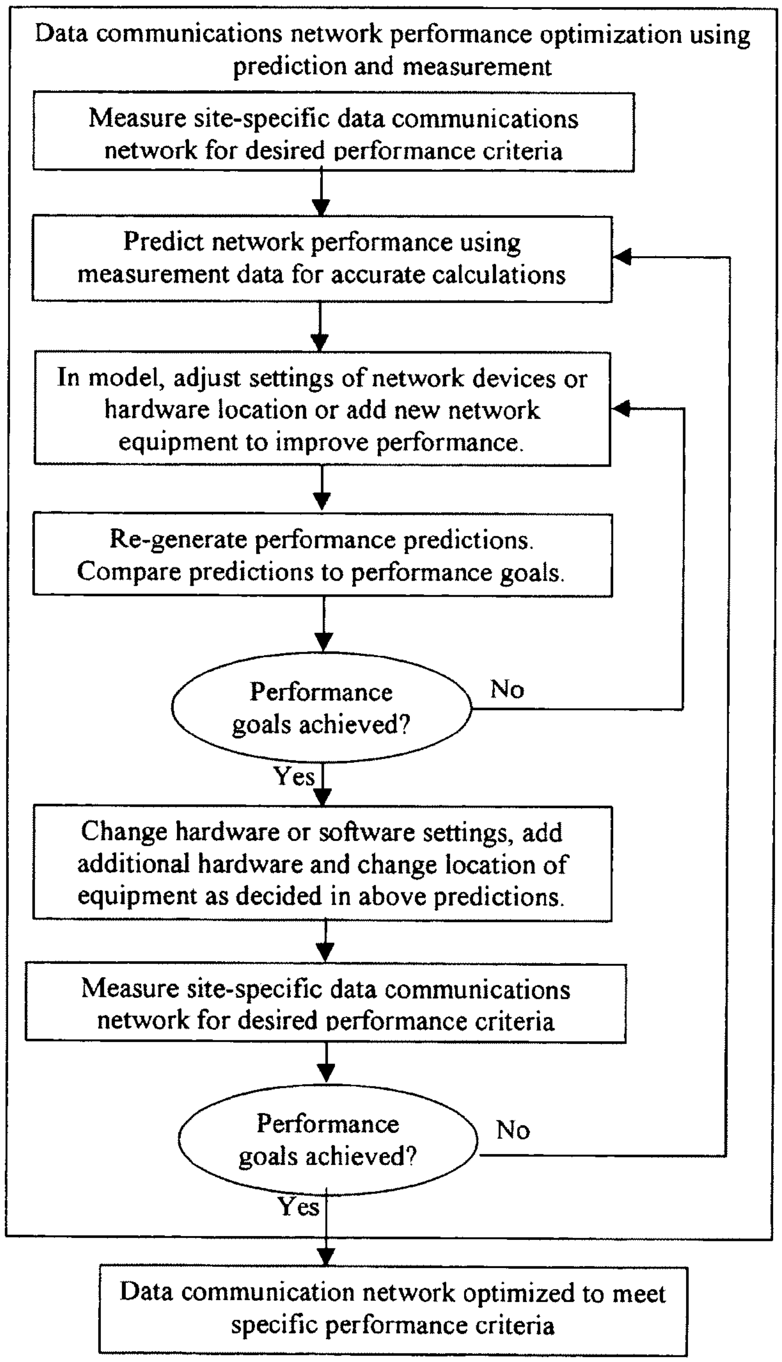


Figure8: Method for optimizing a data communications network using predictions and measurements.



SYSTEM AND METHOD FOR DESIGN, TRACKING, MEASUREMENT, PREDICTION AND OPTIMIZATION OF DATA COMMUNICATION NETWORKS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to application Ser. No. 09/318,842, entitled "Method and System for Managing a Real Time Bill of Materials," filed by T. S. Rappaport and R. R. Skidmore, now U.S. Pat. No. 6,493,679, Ser. No. 09/318,841, entitled "Method And System for a Building Database Manipulator," filed by T. S. Rappaport and R. R. Skidmore now U.S. Pat. No. 6,850,946, Ser. No. 09/318,840, entitled "Method and System For Automated Optimization of Communication component Position in 3D" filed by T. S. Rappaport and R. R. Skidmore, now U.S. Pat. No. 6,317,599. Pending application entitled "Method and System for Designing or Deploying a Communications Network which Allows Simultaneous Selection of Multiple Components" filed by T. S. Rappaport and R. R. Skidmore, Ser. No. 09/633,122, filed on Aug. 4, 2000, as well applications entitled "Method and System for Designing or Deploying a Communications Network which Considers Frequency Dependent Effects", Ser. No. 09/632,121, filed by T. S. Rappaport and R. R. Skidmore on Aug. 4, 2000 now U.S. Pat. No. 6,625,454, as pending application entitled "Method and System for Designing or Deploying a Communications Network which Considers Component Attributes", Ser. No. 09/632,853, filed by T. S. Rappaport, R. R. Skidmore, and Eric Reifsnider on Aug. 4, 2000, as well as application entitled "Improved Method and System for a Building Database Manipulator", Ser. No. 09/633,120, filed by T. S. Rappaport and R. R Skidmore, now U.S. Pat. No. 6,721,769 and pending application entitled "System and Method for Efficiently Visualizing and Comparing Communication Network System Performance", Ser. No. 09/632,803 filed by T. S. Rappaport, R. R. Skidmore, and Brian Gold on Aug. 4, 2000, and co-pending application "Method and System for Automated Selection of Optimal Communication Network Equipment Model, Position and Configuration in 3-D", Ser. No. 09/667,689, filed by T. S. Rappaport, R. R. Skidmore, and P. SheethalNath filed concurrently, the subject matter of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to the field of communications networks, and more specifically to the design thereof, and the measurement, visualization, prediction and optimization of the performance of data communication networks. A method and system to predict, visualize and optimize the performance of data communication networks is used to design, measure, monitor, troubleshoot and improve these data networks using an accurate site-specific model of the physical environment and the components comprising the data network.

2. Description of the Related Art

Communications networks are used to send information from one place to another. This information often takes the form of voice, video or data. To transmit information a communications network breaks down a message into a series of numbers. These numbers describe how to construct the information using some predetermined method. For example, the numbers could represent digital samples of the

signal voltage that should be applied to a speaker so that the speaker reproduces the sound of the voice, as shown in FIG. 1. The information is in this case the voice message, which was transmitted over the communications network.

The process of representing information can be analog or digital. In an analog communications network the message that is transmitted is a continuously changing number. In a digital network, numbers that change at discrete, regular intervals, instead of continuously represents the message. The signal is represented by a single number each interval. This number may be converted to a binary form so that the entire message can be represented as a finite number of ones and zeros. Each binary digit in the message is called a bit. These bits are transmitted and interpreted by the receiver as the message. Binary and digital versions of a signal are shown in FIG. 2.

Data communication networks are a specific type of communication network that transmit digital information, represented as bits or bytes (a group of 8 bits), in an indoor or outdoor, wired or wireless network from a transmitter to a receiver. While conceptually simple, the means of transmitting the data from some point A to some point B are complicated and varied in implementation. Hundreds of protocols, hardware devices, software techniques and programs exist to handle how data is sent correctly and efficiently. The exact performance of a given data communication network is extremely difficult to predict or even measure because of this complexity and additionally because of the performance effects of the time varying nature of data communications networks and the channels they operate in.

Data communication network can be classified as either a circuit switched or a packet switched network. Both network types use channels to transmit information. A channel is a named communications path between users of a communications network. A channel may consist of many different individual hardware devices and is a specific route between a transmitter and a receiver. In a circuit switched network, information is transmitted by way of an exclusively reserved channel. A network channel is reserved for the sole use of a single transmission and bits are sent all at once. An example of this is the transmission of a document using a fax machine. In this case the fax machine converts the image of the document into pixels. Each pixel is a small, dot-sized, rectangular piece of the paper. Each pixel is considered to be either black or white. The data that will be transmitted is a series of bits that represent whether each dot is black or white. When the message (in this case an image of a document) is ready to be sent from one fax machine to another, a telephone circuit is dedicated to the data transfer by placing a telephone call on the plain old telephone system (POTS) communications network. The telephone line is used exclusively by the fax transmission, making it a circuit switched transmission. After establishing a connection, all data is sent from the first fax machine to the second in a single, long stream of bits. The bits in this case are transmitted as different frequency tones on the telephone line. A high pitched toned may represent a "1" while a low pitched tone may represent a "0." The receiving fax receives the bits of the message by translating the series of high and low pitch tones into data bits. The receiving fax machine will then be able to reconstruct a copy of the original document by drawing a black dot at the locations indicated by the data bits.

Packet switched networks are another type of data communication networks in which all data bits are transmitted as many, small chunks of data bits called packets and sent individually from one location to another. A packet is a

self-contained portion of a full message that is made up of a header, data bits, and sometimes footer. The packet contains information in the header and footer that allows the data communications network to properly transmit the packet and to know of which message the data in the packet is a part. The header generally is labeled with an identifier that the network uses to forward the packet to the correct receiver. The header and footer information are often used to reassemble the packet with other packets to reform the original message and to check if errors were made in the transmission of the packet. The receiver can assembles all received packets into the original message by throwing away the header and footer headings and reassembling the data bits from all packets into the original message.

Packet switched networks are classified as connection oriented or connectionless depending on how the packets are transferred. In connection-oriented networks, a network channel is used predefined for each transmission. While this transmission can consist of multiple packets, the route from transmitter to receiver is already established, so that all packets sent on this channel can immediately be sent directly to the receiver. Whereas, in connectionless networks, packets are sent simultaneously on a shared channel in multiple transmissions. In this case, packets require an identifier that gives the address of the receiver. This address is understood by the communications network to allow the packet to be properly sent to the correct receiver. Since each packet can be transmitted separately and thus interleaved in time with packets from other transmissions, it is generally more efficient to use a connectionless transmission method when using shared network resources.

An example of a connectionless, packet-based transmission is a file transfer between two computers on an internet protocol (IP) based, Ethernet network that both computers are attached to. In this case, the file that is to be transmitted is fragmented at the transmitter into appropriate packets and labeled with the IP address, which is the identifier used by the network to forward the packet to the correct receiver. The packets are then sent from the transmitting computer to the receiving computer. The Ethernet network is capable of supporting multiple file transfers from many different computers all using the same network by controlling the flow of packets from each destination in a shared fashion. The receiver then assembles the packets into an exact copy of the original file, completing the transmission.

All data networks utilize some form of communication protocol to regulate the transmission and reception of information. A protocol is the set of rules that all hardware and software on a communication network must follow to allow proper communication of data to take place. Many hundreds of protocols are in active use today in the worldwide exchange of information. Some of these protocols, such as the Transport Control Protocol (TCP) or the User Datagram Protocol (UDP), define the way in which the network is accessed. Other protocols, such as the Internet Protocol (IP) or the File Transfer Protocol (FTP), define how messages and packets are formatted, transmitted, and received.

All data communication networks may be analyzed in some fashion to evaluate the efficiency and performance of the network as well as to confirm the network is functioning properly. In order to evaluate the functionality of these data networks, certain performance criterion is used. These performance criteria include, but are not limited to: throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter,

bandwidth delay product and handoff delay time. Each performance criterion specifies a different performance parameter of a data communications network. These criterions are further described below.

A link is a portion of a path followed by a message between a transmitter and a receiver in a data communications network. Network connection often consists of individual devices relaying network packets from the transmitter to the receiver. This means a network connection can consist of several actual transmissions between the original transmitter and the intended receiver. Each individual relay is called a link. Typically a full network connection consists of several links. Performance criteria can be measured for each individual link.

Throughput is a measurement of the amount of data, which can be transmitted between two locations in a data network, not including header, footer or routing information bits. It is generally measured in bits per second (bps) and can be specified for hardware, software, firmware or any combination thereof that make up a connection between transmitter and receiver in a data communication network. Bandwidth is similar to throughput as it is defined for data communication networks. Bandwidth is the raw data rate that may be sustained by a given communications network and is generally slightly higher than throughput. For instance, an Ethernet link may be rated for a 10 Mbps bandwidth but a measurement of an actual file transfer may show that the rate at which data can actually be transferred between two computers using that same link is only a throughput of 6.8 Mbps as is taught in Peterson, L. L. and Davie, B. S., *Computer Networks: A Systems Approach*. San Francisco: Morgan Kaufmann Publishers, 2000.

Quality of service (QoS) is a term that is used to describe networks that allocate a certain amount of bandwidth to a particular network transmitter. Such a network will allow a transmission to request a certain bandwidth. The network will then decide if it can guarantee that bandwidth or not. The result is that network programs have a reliable bandwidth that can more easily be adapted to. When the quality of service of a connection is measured, the bandwidth that the network claims to offer should be compared to the actual bandwidth for different requested bandwidths.

FIG. 3 illustrates the difference between bits, packets, and frames. Various error rates are defined for data communication networks for bits, packets and frames. Bits are the core of packets and frames. The bits are the actual message data that is sent on the communications network. Packets include the data bits and the packet header and packet footer. The packet header and packet footer are added by communications network protocols and are used to ensure the data bits are sent to the right location in the communications network and interpreted correctly by the receiver. The packet header and packet footer are also used to ensure that packets are sent correctly and that errors are detected should they occur. Frames are simply series of bits with a certain pattern or format that allows a receiver to know when one frame begins or ends. A bit error rate is the percentage of bits that reach the receiver incorrectly or do not reach the receiver as compared to the number of bits sent. Packet error rate or dropped packet rate is the percentage of packets that reach the receiver incorrectly or do not reach the receiver as compared to the number of packets sent. A frame error rate is the percentage of frames that reach the receiver incorrectly or do not reach the receiver as compared to the number of packets sent.

Several terms are used to quantify the delay times of certain network events and may be expressed in time units

of seconds. Packet latency is the time required to send a packet from transmitter to receiver, while Round Trip Time (RTT) is the time required for a packet to be sent from transmitter to receiver and for some sort of acknowledgement to be returned from the receiver to the original transmitter. Propagation delay, transmission delay, processing delay, and queuing delay describe the time required for different portions of a packet transmission to occur. The packet latency and round trip time of a network connection is found by summing the propagation delay, transmission delay, processing delay and queuing delay of either a one way or round trip network connection. Propagation delay is the time required for a packet to traverse a physical distance from the transmitter to the receiver. Transmission delay is the time required from when the first bit of a packet arrives for the last bit of the same packet to arrive. Processing delay refers to the time required to subdivide a data message into the individual packets at the transmitter, and to the time required to recreate the full data message from the data packets at the receiver. Queuing delay refers to the time spent waiting for shared resources to be freed from use by other transmissions. These delay times are all useful for evaluating different aspects of a data communications network performance.

Two other network performance criteria are packet jitter and bandwidth delay product. Packet jitter is the variation in the arrival time of packets that are expected to arrive at a regular rate and is typically measured in time units of seconds. A bandwidth delay product is the number of bits that can be sent from a transmitter before the first bit sent actually reached the receiver. The bandwidth delay product is found by multiplying the packet latency of a certain link by the bandwidth of the same link.

Handoffs occur in wireless data networks when a user moves out of range of one access point and into range of another access point. In this situation, the first access point must pass the responsibility of delivering data to the wireless user to the second access point. The handoff time is the amount of time required by an access point to coordinate with another access point to allow a wireless user to connect from one access point to another access point.

Software utilities and hardware devices have been developed to measure the performance statistics of data communication networks throughout the lifetime of data communication networks. Some of the more common and relevant tools are briefly described here.

A large number of command line tools are available to quickly allow a computer user to measure the approximate network performance a connection. Many command line programs are widely used on Windows, UNIX, and Macintosh operating systems and are somewhat useful for diagnostic and troubleshooting work on data networks. Examples of these command line programs include ping and traceroute. Using the ping command line program, it is possible to measure approximate data latency between different data network devices and confirm that a network connection is available between the two devices. Network connections often consist of individual devices relaying network packets from the transmitter to the receiver. This means a network connection can consist of several actual transmissions between the original transmitter and the intended receiver. Each individual relay is called a link. Typically a full network connection consists of several links. Thus, using traceroute, a probable path from relaying device to relaying device between the transmitter and the receiver can be determined so that the exact links used by the network transmissions are known. Additionally, using traceroute, the time required to traverse each individual link can be measured, and individual links that may not be functioning properly can be identified.

Various command line tools that are not included with operating systems have also been developed for somewhat more accurate, though still approximate, network measurement tasks. Some examples of these tools include ttcp, and tcpdump. ttcp stands for Test TCP http://www.pcausa.com/Utilities/pcattcp.htm and is a free utility originally written for the BSD Linux operating system, but is now available for other UNIX operating systems as well as Microsoft Windows. ttcp is a basic point-to-point throughput measurement program that allows the user to control buffer sizes, various low level TCP or UDP options and control the exact data that is sent.

tcpdump is a simple utility from the class of tools called packet sniffers. Packet sniffers allow a network administrator to view the content, including header and footer information, of actual packets on a network. tcpdump allows a user to view (or "sniff") packets that are received by a host (though not necessarily intended for that host) and display all headers that match a certain user configurable pattern. tcpdump is a useful tool for troubleshooting network connections because it allows the user a direct view of the exact network traffic.

Pathchar is a UNIX command line utility which is capable of measuring the throughput between each network relay device (e.g. a router, hub or switch) in a data communications network by varying the size of the test packets that it transmits and measuring the latency of that packet transmission to various network points. The tool functions very similarly to traceroute but adds the ability to measure throughput (albeit indirectly), not just latency. Pathchar is only limited by the network hardware in the links it measures. The program needs a hub, switch or computer to transmit an acknowledgement to the test packets. This means that hidden links that do not transmit acknowledgements such as Ethernet bridges can not be measured individually by pathchar.

Several companies produce network measurement, monitoring, tracking and forecasting utilities. Some of the commonly used utilities are discussed below. The tools selected are illustrative of the state of the art of network performance measurement and asset tracking.

netViz, made by netViz Corporation, is a visual database program that allows a network administrator to track network equipment in terms of its physical location and in terms of its logical layout. This program allows the user to input the settings, locations, and configurations of the network and track the assets in your network. The tool is capable of storing this data in a two dimensional geographic map or floor plan of a building, but can not track devices in a three dimensional manner. The tool, also, does not provide network testing, measurement or monitoring features, nor does it support communication prediction or performance visualization capabilities for data communication networks. It is simply a database for accurate and useful tracking of assets.

NetIQ Corporation (was Ganymede Software, Inc.) makes a network monitoring and forecasting tool called Chariot. Chariot is able to measure throughput and many other network statistics for all popular network types, operating systems and protocols available today. The program uses a server and several small agent programs to collect data. The server checks each agent, installed on user's computers throughout the network, at regular intervals and uses them to measure network characteristics while storing

the results on the server. These agents can measure the network connection to the server or to one another and are capable of simulating the traffic patterns of any network program and any desired usage pattern of one or more hypothetical users. The program is also capable of using the measured data to forecast expected network traffic and conditions.

Visonael Corporation (was NetSuite Development Corporation) makes several network tracking and measurement products, including NetSuite Audit, Design and Advisor. These software products are capable of automatically detecting the network equipment in use. This information as well as manually entered information can then be placed in a physical or logical diagram of the network. Visonael also offers a product to verify that networks have been configured properly and can make recommendations for configuration changes and upgrades to your network. The software products are unable to predict or measure the performance in a site-specific manner and are not capable of predicting the performance of wireless based data communication networks.

SAFCO Technologies, Inc. (now a part of Agilent Technologies) has recently created several wireless data measurement and prediction products. SAFCO makes a product called DataPrint, which is used to measure various data performance parameters of mobile telephone data networks. Their WIZARDS product also supports analysis of the effects of wireless data transmission on the overall capacity and Quality of Service for a wireless telephone network.

Wireless Valley Communications, Inc. has created a new concept called SitePlanner, which is capable of measuring and tracking the site-specific network performance of a data communications network in a physically accurate three-dimensional model of an environment. SitePlanner uses a software module called LANFielder to measure throughput, packet latency and packet error rates for any wired or wireless network connection in any Internet Protocol (IP) data communications network. Additionally, SitePlanner allows a full network to be modeled in a physically accurate manner so that precise measurements and performance predictions can be made in a site specific way. SitePlanner also allows a logical layout of a network to be stored simultaneously with a physical layout. The tool also stores both a logical interconnection and a site-specific model of any communications network using a Bill of Materials format.

In addition to network measurement and asset management tools, a good deal of research has taken place in the field of wireless data communication network performance. The research described below represent the work, which pertains to the field of this invention.

Xylomenos and Polyzos have explored the performance of UDP and TCP packets sent over several fixed, IEEE 802.11 wireless LAN network connections in Xylomenos, G., Polyzos, G. C. "TCP and UDP Performance over a Wireless LAN" *Proceedings of IEEE INFOCOM,* 1999. The research has focused on throughput limitations caused by software implementation issues and operating system shortcomings. The researchers used their own modified version of the command line utilities ttcp, tcpdump and nstat under Linux to perform UDP and TCP throughput tests. All measurements were taken between three fixed locations and focused on varying the wireless LAN card types (PCMCIA or ISA) and the end-user computer hardware (i.e. Pentium 150 with 48 MB of RAM vs a Pentium 200 MMX with 64 MB of RAM). The conclusions the researchers make are recommendations for changes in the implementation of network protocols and linux operating system enhancements. The measurements did not consider the effects of different physical locations or the effect of variations in the wireless communications channel on the network throughput.

Maeda, Takaya and Kuwabara have published a measurement of wireless LAN performance and the validity of a Ray tracing technique to predict the performance of a wireless LAN network (Maeda, Y., Takaya, K., and Kuwabara, N., "Experimental Investigation of Propagation Characteristics of 2.4 GHz ISM-Band Wireless LAN in Various Indoor Environments," *IEICE Transactions in Communications, Vol.* E82-B, No. 10 Oct. 1999). The measurements were tracked in a small, highly radio frequency (RF) controlled environment and indicated that the wireless LAN throughput and BER were correlated to the delay spread of the wireless channel. The researchers have not however presented any way to actually predict a bit error rate or throughput from the predicted delay spread profile output by a ray tracing technique.

Duchamp and Reynolds have presented IEEE 802.11 wireless LAN, packet throughput measurement results for varying distances in Duchamp, D., and Reynolds, N. F., "Measured Performance of a Wireless LAN," *Local Computer Networks,* 1992. *Proceedings., 17th Conference on,* 1992. These measurements were performed in a single hallway. Thus, these measurements, too, suffer from failing to measure a representative environment. The researches did not present a model to predict their results nor did they attempt to validate any sort of computer prediction technique.

Bing has also presented measured results of the performance of IEEE 802.11 Wireless LAN in "Measured Performance of the IEEE 802.11 Wireless LAN," *Local Computer Networks,* 1999. *LCN '99. Conference on,* 1999. Bing presents delay and throughput measurements as well as theoretically based throughput and delay time tabulations for various wireless LAN configurations. The results are given as optimal results, however. All measurements were performed in such a way that the wireless channel had the least possible effect on the overall throughput and delay times. Therefore, the results presented are an upper bound on best possible results and do not extend into a site-specific wireless LAN performance prediction technique.

Hope and Linge have used measurements to calculate the needed parameters for predicting the coverage area of a Wireless LAN network in an outdoor environment by using the Okumura model. The researchers have made outdoor measurements with standard IEEE 802.11 wireless LAN modems to calculate the needed parameters of the Okumura model and have presented these results in Hope, M. and Linge, N., "Determining the Propagation Range of IEEE 802.11 Radio LAN's for Outdoor Applications," *Local Computer Networks,* 1999. *LCN '99. Conference on,* 1999. Using these results, The coverage area outdoors could be calculated. However, the results do not allow the user to predict the performance in terms of throughput or latency of a wireless LAN.

Several patents related to, and which allow, the present invention are listed below:

U.S. Pat. No. 5,491,644 entitled "Cell Engineering Tool and Methods" filed by L. W. Pickering et al;

U.S. Pat. No. 5,561,841 entitled "Method and Apparatus for Planning a Cellular Radio Network by Creating a Model on a Digital Map Adding Properties and Optimizing Parameters, Based on Statistical Simulation Results" filed by O. Markus;

U.S. Pat. No. 5,794,128 entitled "Apparatus and Processes for Realistic Simulation of Wireless Information Transport Systems" filed by K. H. Brockel et al;

U.S. Pat. No. 5,949,988 entitled "Prediction System for RF Power Distribution" filed by F. Feisullin et al;

U.S. Pat. No. 5,987,328 entitled "Method and Device for Placement of Transmitters in Wireless Networks" filed by A. Ephremides and D. Stamatelos;

U.S. Pat. No. 5,598,532 entitled "Method and Apparatus for Optimizing Computer Networks" filed by M. Liron et al.

U.S. Pat. No. 5,953,669 entitled "Method and Apparatus for Predicting Signal Characteristics in a Wireless Communication System" filed by G. Stratis et al.

U.S. Pat. No. 6,061,722 entitled "Assessing Network Performance without Interference with Normal Network Operations" filed by W. J. Lipa et al.

U.S. Pat. No. 5,831,610 entitled "Designing Networks" filed by D. L. Tonelli et al.

U.S. Pat. No. 5,821,937 entitled "Computer Method for Updating a Network Design" filed by Tonelli et al.

U.S. Pat. No. 5,878,328 entitled "Method and Apparatus for Wireless Communication System Organization" filed by K. K. Chawla et al.

An existing product, SitePlanner, described in patent application Ser. Nos. 09/352,678, 09/221,985, 09/318,842, 09/318,841, 09/318,840, and other inventions cited previously, are useful for designing, measuring and optimizing communication networks because the products can predict radio frequency effects directly relevant to any communication network for any physical location. That is, using information about the physical layout of any communications network and the configuration of its hardware, prior art can provide a visual display of the expected received signal strength intensity (RSSI), signal to noise ratio (SNR), relative received power intensity, best server, and equal power location, as well as other useful parameters for voice and data networks, for any modeled physical location. These statistics can be predicted for the forward link (from a transmitter to a receiver), or for the reverse link (replies from the original receiver to an original transmitter) directions for wireless networks. The site-specific nature of these predictions translates directly into quick and useful visualizations of the quality of a communication network. However, the prior art does not consider methods for properly modeling (e.g. predicting) the complexities that go into determining the values for actual network operating performance parameters that are simultaneously affected by multipath propagation, multiple interfering data transmissions from multiple sources, signaling protocols, equalization methods, and the like. Predicting bit error rates, data throughput, delay, and quality of service metrics in a 3-D physical model of an actual site-specific environment is a very difficult task, and one which has not been solved heretofore, since different modem vendors have different and often-times proprietary methods for mitigating or dealing with multipath, multiple access interference, protocol type, packet size, and noise. That is, the state of the art shows how to measure and display and make predictions for basic communication metrics but does not provide specific prediction algorithms for a wide range of important data network performance parameters in a reliable, site-specific manner. Simply put, a wireless network performance prediction engine, which is able to consider an accurately modeled 3-D physical environment, and which exploits knowledge of specific component layouts, is not found in the prior art and is not obvious due to the complex nature of having to account for all possible physical, electrical, and logical factors for all components in a network, as well as the factors within the channel of a wired or wireless network, that lead to actual network performance.

Prior published papers in the area of communications networks do not demonstrate the ability of any invention to accurately predict three dimensional, site-specific network performance criteria. The paper mentioned earlier by Maeda, Y., Takaya, K., and Kuwabara, N., "Experimental Investigation of Propagation Characteristics of 2.4 GHz ISM-Band Wireless LAN in Various Indoor Environments," *IEICE Transactions in Communications*, Vol. E82-B, No. 10 Oct. 1999 has demonstrated the ability to predict the delay spread of a wireless channel and that the prediction correlates well with throughput, but the described method is not actually able to predict throughput or any other network performance criteria. While some prior art has demonstrated the ability to track network assets in a two dimensional manner with some physical accuracy, these products have not contemplated the ability to predict future network performance for similar or different physical environments (e.g. installations). Many products allow the measurement of network performance criteria, but no prior art has contemplated a 3-D representation of the physical environment with the physical installed base of components, for the purpose of predicting network performance parameters. Furthermore, no tool or invention exists that can directly measure, track the assets of, predict the network performance criteria of, and visualize the network performance criteria of a data communications network in a three-dimensional site-specific manner.

Furthermore, none of the prior art has considered an invention that can perform precise, site-specific, three dimensional performance prediction of complicated network parameters using a priori measurements from an existing network, or by using the site-specific layout details of particular components within a data communications network. Furthermore, none of the prior art has autonomously measured site-specific network performance parameters from an actual network system or subsystem using a system of agents, and then applying the specific 3-D locations and measured results of those measurement agents to create a 3-D prediction model for future network performance in the same, similar, or different physical environments. Furthermore, none of the prior art has developed a hierarchical system of measurement and prediction engines, that have the ability to measure network performance parameters in the field and have the ability to produce a predictive engine for network performance parameters that can be shared with remote prediction engines, for the purpose of measuring and predicting network performance in a 3-D site-specific manner.

The present invention extends the prior art in a non-obvious way to provide wireless and wired network performance prediction, visualization and measurement for important data communications-specific performance criteria, also called performance parameters, such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time in a site-specific, three dimensionally accurate manner. The invention contemplated here allows novel distributed measurement techniques for the above performance parameters. Furthermore, prediction methods for the above performance parameters are created, which use network measurements or applied values derived from other means, and which also use the

radio frequency environment, the 3-D physical network layout, the channel propagation characteristics of a site-specific environment, and the specific physical layout of components, for the computation of predicted performance parameter values.

SUMMARY OF THE INVENTION

The present invention is capable of predicting, measuring, and optimizing the performance of a data communications network. The invention is capable of representing a detailed layout of a fully deployed or contemplated communications network within a physically accurate computer representation or model of a three dimensional environment. This allows the invention to store measurements and determine performance predictions within a site-specific representation of the physical environment, while using specific information about the network entities, components, subsystems, and systems used to create the actual or contemplated network. Measurement agents, with known or assigned 3-D position locations, are used to measure in-situ performance parameters that are transmitted to a server processor. The server processor has an accurate 3-D model of the environment, and is able to process the measured data, and is also able to provide predictive models using site-specific information that may be independent of or may make use of measured data. The server process is able to communicate with other server processors in a hierarchical manner, such that data fusion from many remote or collocated networks may be assembled and used for display and cataloging of measurements that may or may not be used for creation of predictive performance models. Alternatively, each server processor is able to compute predictive performance models without the use of measured data, by simply considering the site-specific layout of physical components, as well as the specific delay times, transit times, propagation effects, and multipath and noise factors within the physical network.

The invention can predict throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time in a site-specific, three dimensional model of any environment. The invention can measure and predict all of the above performance criteria and store the results in the physically accurate three-dimensional model of a data communications network and the environment in which it is installed. Further, the invention can display the measured and predicted performance criteria for any data communications network in the three dimensions, site-specific model of the environment. These capabilities provide a powerful design environment for wired and wireless networks, which allows one skilled in the art to quickly and easily design, measure, predict, optimize and visualize data network communication performance criteria in a three dimensional, site-specific manner using methods never before contemplated.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1: Example transmission of data over a communications network

FIG. 2: Creation of a digital signal from an analog signal

FIG. 3: Illustration of the difference between bits, packets and frames.

FIG. 4: Illustration of the data displayed in each node of the Tree View of a data communications network.

FIG. 5: Method for creating a 3-D site-specific model of the environment

FIG. 6: Method for optimizing a data communications network using predictions

FIG. 7: Method for optimizing a data communications network using measurements

FIG. 8: Method for optimizing a data communications network using predictions and measurements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The present invention contemplates the abilities to design, measure, predict and optimize the performance of a data communication networks. The invention uses an accurate computer generated three-dimensional model of a communications network stored in a computer database environment. The invention allows the user to place the network cables, hubs, routers, switches, bridges, wireless access points, amplifiers, splitters, antennas (point, omnidirectional, directional, leaky feeder, distributed, array, etc.) transceivers, terminators and other communications and computer networking equipment in their actual modeled physical locations. The present invention uses this highly accurate model of the physical layout of infrastructure to allow a user to visualize, predict and optimize the performance of any communication network in any 3-D site specifically modeled physical location.

The present embodiment of the invention is capable of modeling the site-specific communications network hardware from both a logical connection and a physical location perspective. The invention uses well-known hierarchical, logical connection concepts (sometimes called topological layout) suited for data communications networks in combination with a physically accurate, site-specific model of the data communications network. Previous inventions focus on only the topological, or relational, layout of network components with one another. This invention uses specific 3-D modeling and, therefore, allows highly accurate asset management and facilities tracking of actual installed equipment while simultaneously providing for network performance prediction, measurement, and design capabilities that exploit the exact physical dimensioning of the network. In addition, the invention simultaneously stores an inventory of important network-specific and equipment-specific characterizations of all objects used in the network, such as vendor, model number, network hardware type, operating system version, firmware and software type and version. The hierarchical, tree based model of the network is termed the Layout View. The physically accurate, site-specific model of the network is termed the Site View, whereby the attributes of each device can be displayed, stored or printed by selecting a particular item or node within the 3-D environmental model. Further, network hardware and software components can be interactively replaced, removed, reconfigured or moved to a new location in real-time using either the Layout View or the Site View. Each of these ways of tracking and designing a network in a 3-D site specific model of the environment with accurate dimensioning of true spatial position are further described below and are used to create a Bill of Materials for the modeled data communications network, whereby a preferred embodiment is described in co-pending patent application "Method and system for designing or deploying a communications network which considers component attributes," filed on Aug. 4, 2000.

An example of some of the information contained in the Layout View, hierarchical layout of a data communications network is shown in FIG. 4. In the figure, a tree structure is used to display all hardware in the network. Each node in the tree contains information which is used to track the true physical location, logical layout and electrical, optical and electromagnetic connections for the data communications network hardware as well as any version numbers and settings of software or firmware running on that network equipment and the known performance parameters of that equipment, including the device throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time.

The Site View of the invention has a physically accurate, three-dimensional modeling capability to display all network devices in a site-specific model of the environment that the network is located in. That is, the preferred embodiment of the invention allows each modeled hardware and software device to be placed in a three-dimensionally accurate manner and to track attributes of that device relevant to data communications networks. These key attributes include such items as the hardware type, hardware configuration, software type, software configuration, operating system version, as well as upper, lower and "typical" specifications for each component. These specifications may include important device or network subsystem operating parameters, such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time. As described below, the Site View supercedes prior art described in previous co-pending patent applications by Wireless Valley Communications, Inc by hereby considering the difficulties and solving data network prediction, design and optimization problems for more complicated data communication networks. Specifically, this new invention considers physical, site-specific modeling techniques and performance prediction methods and design methods for data network systems, both wired and wireless, which have performance characteristics that are based on much more complicated physical factors than just radio signal strength, interference, or multipath alone. In particular, for data communication networks, many additional factors, which relate to particular network equipment or modem designs, such as packet size, equalizer deployment, modulation methodology, source and error coding methods, packet protocols, as well as the number of co-channel network users, the type of persistency used for packet retransmission, or the multipath propagation effects in a wireless system, provide additional factors that must be considered in the design of a communication network that is designed for data traffic as opposed to simply voice traffic.

One difficulty that today's network designer or network system administrator faces is that most networking equipment uses proprietary, non-public methods for implementing various network devices, and these methods vary by specific vendor. Thus, it is difficult to form reliable prediction models by just using basic physical propagation models in a wireless network, for example. As data transmission technologies such as Bluetooth, DSL, Voice over IP, and future packet-based cellular radio network architectures proliferate, the ability to predict and measure specific network performance parameters will become increasingly important, and the ability to properly incorporate measurements into 3-D prediction models for performance parameters will be important for proper network deployment.

This invention considers attributes relevant to packet-switched data communication networks, which require more extensive and non-obvious modeling when compared to traditional cell phone or telephone voice communication systems that are circuit switched and use a dedicated single user (or bounded number of users) per assigned operating channel. Data communication networks have performance criteria that are specific to packet-based systems and that are not useful to all types of communication networks contemplated previously. For this reason, the preferred embodiment of the invention can additionally predict the throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time, based on the specific physical and spatial location of each network component, as well as the physical, electrical, and logical attributes of the specific components. The performance prediction methods take into account all devices and network equipment, including the physical locations within the 3-D modeled environment, using the constructed Bill of Materials of the network within the 3-D modeled environment, and is capable of performance predictions for any desired location in the modeled network and environment, where a location may be within a room, at a particular location in a room, within a building, or in an outdoor region of varying granularity, depending on the requirements of the user.

Prediction of throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time and other performance parameters may be carried out by predicting the performance for all wired network components separately from the performance of wireless components, and then combining the results to get the net network performance. To predict the performance of a wired communication link, it is important to combine the known effects of each piece of wired equipment for the specific network settings, also known as operating or performance parameters, such as protocol type, data type, packet size, and traffic usage characteristics, firmware type, operating system type, typical network performance characteristics, and typical, average, peak, and minimum traffic load on the network. For wireless network components, additional factors concerning propagation, signal strength, interference, and noise must be considered.

The preferred embodiment of the invention allows data communication networks to be accurately characterized for performance prediction in a number of novel ways.

First, performance prediction may be based on field measurements from an actual network, where prediction models are formed from some fit to measured data (an empirically-based model). These field measurements may be made manually, or autonomously, using data collectors, or agents, that continually measure and update the specific network performance metrics that are observed within the physical environment. These data collectors are able to measure, or are assigned, specific 3-D position locations within the physical environment, such position locations corresponding to known positions in the computer model which is used to model the physical environment of the

network, and which are known or which are transmitted to a measurement server. The data collectors may be individuals who manually or automatically record or collect observed network performance such as one or more of the aforementioned performance parameters, or the measurement agents may be software or hardware or firmware applications that run on top of network applications for the purpose of routinely measuring for one of more of the numerous network performance parameters listed previously. The agents may be fixed, or may be portable, and may have position location devices, such as GPS or inertial navigation, or an internal map which is activated by a user, so that the position location of the measurement is sent to a server processor. The agents are presumed to have two-way communication with a server processor that may be collocated or remotely located. Measurements from one or more data collectors are routinely or periodically collected and then transmitted, either by wireless or wired means, or by real-time or stored means, to a server processor which is either collocated, or remotely located, from one or more of the measurement agents. For example, the measurements may be recorded by autonomous agents and then transmitted over a fixed network to a processor that integrates all measurements and computes statistics for observation. The measurement sources have known positions in 3-D, or may not be known and used to form a gross estimate of observed network performance. The collected measurements may be sent in real time, stored and forwarded, or sent as file transfers via many means, such as via email, over the world wide web, via wireless, wired or optical links, or in a storage device. This "in-situ" measurement data is passed, with the 3-D position location when available, to the server, which catalogues and processes the specific measurement information. Using the measurement information from the data collectors, the server is able to provide a predictive model by using knowledge of the physical 3-D environment, and by fusing the many collected inputs into a simplified model of performance that is related to the 3-D physical representation of the world.

In the preferred embodiment of the invention, the server stores and processes the physical location of all measurement devices (where available) as well as all network components and their electrical, logical and technical configuration, while also considering cost and maintenance issues associated with each network component. Using the preferred embodiment, a data communications network can be designed, deployed, tested, predicted, measured, optimized and maintained by collecting the measured data from one or more agents, and processing them at the server to determine a proper prediction engine that allows future network layout with a desired outcome prior to installation. The server engine is able to display the measured results, in a site-specific manner from each measurement agent (that has site-specific information) so that predictions may be compared to measurements on a visual display of a computer or in a stored means (such as an ASCII file comparing predicted versus measured performance parameters).

It is important to note that each measurement agent may be a server, capable of fusing measurement data with the site-specific 3-D layout of the network components and the physical environment. Therefore, each measurement agent may serve as a centralized processor, as well, so that many different physical locations of a particular network may be measured and predicted for performance. Servers may then be collocated or remotely located from the measurement agents, which collect, display, store and use the measurements to form predictive models. In the case of a remote

server that receives measurement data from measurement agents, it is possible to remotely monitor, and then predict, the performance of a network that is physically very far from the particular server processor.

The measurement agents may be further controlled or configured by the server processor, so that the agents may be tuned or instructed to perform different types of measurements, such as different packet transmission rates, observation intervals, averaging intervals, protocol types, or other sensible changes which those skilled in the are would conceive for proper network optimization.

A second method for predicting the performance of network parameters is through the use of analytical or simulation methods. These analytical and simulation methods are well known, and relate the physical and electrical characteristics of the network channel to the physical and electrical characteristics of the various network components. Through simulation or analysis, it is possible to determine approximations or bounds on the typical values that one would expect in an actual network configuration of specific components. The present embodiment of the invention allows a user to enter the results of such calculations, so that they are applied as inputs to the prediction model. Therefore, a user of the invention may simply enter "blind" values, based on known methods, as a first guess approach to forming a prediction model of network performance. These first-guess values may then be iterated by the invention, based on feedback from the site-specific measurements of the actual network.

A measured set of data for a typical operating environment with multiple transmitters in a wireless or wired network, are recorded, stored and displayed by the invention, as taught in the previous description about the measurement agents and server processors. Then, some form of best-fit algorithm (minimum mean square, median filter, etc.) may be applied to the predictive models provided in the equations taught below to provide a table look-up for determining proper performance values (e.g. proper values for constants or functions in the performance parameter equations listed below) for a particular site-specific network design. This table look up method allows measured data to be translated into values that may then be used to drive predicted data for all subsequent predictions conducted within the same site-specific 3-D environment in which measurements were made. Alternatively, best guess performance metric values, or best guesses for the functions or constants in the equations listed below, may be fed into the invention, either manually or automatically through a storage means or via a wireless or wired means from a remote or collocated location, for a specific 3-D modeled network environment, wherein the predicted performance at any space or location with the 3-D environment is based on the first, best guess, predictive models. As explained subsequently, these initial best guess, or "blind" models may be based on simulation, analysis, or some combination thereof. The empirically-based predictive models and the initial best guess predictive models may be used in subsequent environments, different from the environment for which measurements or best guesses were made, and the invention allows a catalogue of models to be used easily by the user for subsequent network prediction or design. Measurements of actual network performance may then be overlaid and displayed and stored simultaneously with the network prediction parameters, for rapid comparison. Furthermore, optimization routines compute the best values for minimum error for new predictive models that match the measured network performance within the environment. Thus, the

invention allows the user to relate empirically-derived predicted performance parameters or initially guessed network performance parameters within a 3-D site specific configuration of the actual installed or contemplated network, using specific information and physical locations about the network devices and by using the models for wired networks and wireless propagation, multipath, and noise. The model techniques for this invention fuse the many factors that impact network performance into simpler models that support prediction and comparison of measured versus predicted network performance for radio/wireless and wired networks. Thus, performance prediction can be ascertained and compared to measured network performance for use in ongoing network deployment.

Furthermore, by comparing measured network performance metrics to predicted metrics, the invention allows new field measurements to update the previous prediction models in a convenient method, which provides a catalogue of models that is stored and displayed to the user either locally or remotely. Alternatively, using the hierarchy of servers, it is possible to use remotely located servers which compute, transmit, or receive such measurements and predictive models for the remote use, display, measurement and storage of model parameters and results. This is particularly convenient for network administrators who wish to monitor the performance and design of networks that are physically distant from the network of interest.

Measurements of a particular device for desired performance criteria is accomplished either by using the measurement software module available in the preferred invention or by importing a log file from another software or hardware measurement tool. The measurement module within the preferred invention allows the measurement of the performance of any specific portion of a communications network using two or more software programs which are installed and run on either sides of a device or devices. These software programs are called agents. By sending test transmissions between two agents across a specific network connection the preferred invention can measure any particular performance criterion. The results of these measurements are stored for a particular portion of the network.

The preferred embodiment of the invention can also import the logfiles of other measurement programs such as traceroute to measure specific links. This functionality allows site-specific measurements made by external programs to be stored site-specifically. This is accomplished by a two-pass method described in patent 09/221,985, "System for Creating a computer model and measurement database of a wireless communication network" by T. Rappaport and R. Skidmore, filed Dec. 29, 1998. To import a logfile a user simply clicks a point in the model of the environment for each data point to assign a location for each point in the logfile.

In performing network performance measurements, especially for wireless data networks, it is important to know the difference in performance for transmission and reception. This is why the preferred invention can measure the transmission and reception components of the average network statistics. To measure the transmission direction, the size of test packets is varied. By changing the size of the packet sent and the size of the packet returned, the transmission and reception statistics can be separated. This allows a network designer to identify problems in transmission that might otherwise be masked by apparently good reception.

Network performance measurements are not useful if the measurements do not mimic the actual data traffic that a network carries. For this reason, the preferred embodiment of the invention is able to mimic the traffic patterns, network protocols and packet characteristics of actual data. Thus, if web browsing performance is being measured, the invention sends small packets from an access terminal to a web server and returns large packets from that server that are typical of text, image and web script file formats. By measuring the performance of such packets, the invention accumulates accurate network statistics for expected web browsing performance.

The measurements of specific traffic types may also be applied to the use of broadcast or multicast packet performance scenarios. The preferred embodiment of the invention is able to measure performance of multiple transmitters or multiple receivers or both of the same packet information. The performance of this type of transmission are different than point to point measurement because shared resources are used more efficiently in broadcast and multicast scenarios. Thus, the ability of the invention to measure network performance statistics for the overall success of the broadcast or multicast transmission and for each individual transmitter and receiver is quite powerful. This ability allows network designers to better choose which transmitters of multicasts might be redundant or which broadcast transmissions are insufficient to reach all the desired receivers.

In some data communications network, the performance of specific pieces of equipment, such as Ethernet Bridges or even a single cable, is hard to measure because it is transparent to the network layer of a data communications network. For this reason, the ability of the invention to determine the performance of a single device through extrapolation is quite useful. The preferred embodiment of the invention is able to use known performance data for specific pieces of network equipment and extrapolate the contribution of other devices in the network. Measuring and extrapolating enough individual hardware and software links can identify the performance of all network devices. The accuracy and reliability of this procedure heavily depends on an accurate and site-specific model of the data communications network, which the invention possesses.

Extending the extrapolation concept of performance evaluation to the software and hardware components of network equipment demonstrates a further capability of the preferred embodiment of the invention. The invention is able to distinguish in some cases between the performance limits due to software and those due to hardware. For example, in a situation where the transmitter and receiver are the same computer, no hardware is actually involved in the transmission. By measuring network statistics in this situation, one can quantify the performance of just the computer software. By comparing the situation where the transmitter and send are the same to a situation where the transmitter and receiver are different computers the performance of just the computer hardware can be identified. Since the performance of the software in either case will be quite similar, the performance of just the hardware in a connection between two computers can be extrapolated by assuming the software will perform similarly in either case.

Extrapolating the performance of individual network components from measured performance metrics can be time consuming. For this reason, the preferred embodiment of the invention is able to read in data results from a plethora of measurement tools, system utilities and network logfiles to a single internal format. The invention is capable of reading in the output of command line utilities such as ping or ttcp, the logfiles generated by routers and switches such as tcpdump, or even the logfiles of other commercial measurement programs, and these measurement results are

stored for use in the predictive engine. The combination of these imported files to a single internal format allows the invention to combine many different measurements and activity logs into a single set of network statistics. This process means the invention requires fewer active measurement campaigns and more diverse and accurate data for better and more accurate network performance modeling.

Accurate, reliable representations of a data communication network require a large number of measured data points. Hence, the preferred embodiment of the invention collects a large amount of data quickly and easily using various methods as described above. The invention does this by providing remote data collection agents, which can be installed on data access terminals or embedded in hardware, software, or firmware within an actual device in the network. The remote data collection agents respond to a server program (the processing server) that controls the measurements made by the remote agent. That is, the remote agent can be directed to make a measurement to or from any other remote agent or processing server using any desired protocol, traffic type, network setting, or configuration. This process does not require any input from a human user at the remote agent's physical location. The agents simply records the data when asked with the correct settings and reports the results back to a server which stores data from all remote agents and other measurement tools. The server can generate a variety of detailed reports and use the data to make predictions about expected network performance in future. Servers can also function as agents. In this manner, servers can be organized in a hierarchy or a distributed fashion. This allows servers to report measurements to one another and make measurements using other agents or servers. A network designer at a server can then use all collected and reported data to identify problem areas such as fairness or poor distribution of broadcast data, or problem times, such as increased network activity at lunch time with a data communications network.

In order to improve the value of measurement data collected, the preferred embodiment of the invention identifies the exact (if possible) or approximate location of a remote agent. As discussed earlier, remote agents in this case can either be controlled by a user at that physical location, or controlled remotely by a server. In the preferred embodiment of the invention, the agent uses information about the network layout to identify an approximate location. Determining the nearest piece of network equipment and associating the approximate location with the precisely known location of that network equipment accomplishes this. This approximate location can be further refined using dead reckoning, clicking on a location in a map, or using the global positioning system, laser range finders or some other positioning device known now or in the future.

The preferred embodiment of the invention is not only capable of accounting for the effects of different hardware, firmware, software and configuration settings, but it can also predict the effects of just the hardware and firmware, just the software, or of a single configuration setting. The ability of the invention to measure and thus adjust empirically-derived predictions for these effects allows the optimization of the data communications network. By predicting the effects of changing any detailed aspect of the data communications network, a user can immediately visualize the effect of a new component or a setting change. This ability allows a user skilled in the art to design an optimal data communications network by continually making changes and observing the prediction changes.

We now focus on the details for predicting values for network performance parameters based on knowledge of the 3-D site-specific environment as well as the specific components used in the network design.

The throughput and bandwidth of a network are calculated by the invention as functions of any or all of the following operational parameters which impact performance: distance between transmitter and receiver, physical environment specification, packet sizes, error and source coding schemes, packet overhead, modulation techniques, environment, interference, signal strength, number of users, and for wireless networks, the antenna pattern and type, multipath delay, number of multipath components, angle of arrival of multipath components, radio frequency bandwidth, protocol, coding scheme, and 3-D location. In order to predict the bandwidth and throughput of a network connection, the appropriate functions and constants may be calculated from the listed parameters and then predicted for each location and time desired.

For a wired network, throughput (T) or bandwidth (BW) may be derived from a vendor's specification sheet of a product or device, or may be measured in a special laboratory setting. Alternatively, T or BW may be calculated through analysis or simulation, or may be measured in the field using a number of known devices. These means may be used to determine the proper value for T or BW in a network prediction enging such as contemplated here. A formula for predicting the throughput and bandwidth for a wireless data communications channel is shown in equation 1.

$$T \text{ or } BW = C_1[Ad + Bd^2 + C] + C_2[D(RSSI) + E(RSSI)^2 + F) + C_3\sum_{i=1}^{M}(G_iP_i + K_i) \tag{1}$$

where T is throughput, BW is bandwidth, d is the distance between a transmitter and a receiver. RSSI is the received signal strength intensity, which is the power level of the signal at the receiver, either in absolute values or in logarithmic values. A, B, C, C_1, C_2, C_3, D, E, F, K_i, are constants or may represent linear or nonlinear functions of one or more physical or electrical parameters, such as physical environment type, packet size, modulation, modem type, or other parameters that relate the physical, electrical, or logical environment of the network. These constants or functions take on specific functional values depending upon if T or BW is being solved for. The value M may denote a particular number of multipath components from a particular transmitter, as determined by propagation analysis of the channel, or the term may denote a combination of important multipath components from a collection of transmitters, where the term "important" is based on antenna pattern, physical environment distances, and other wireless propagation factors which are well known to one skilled in the art and which are explained below. The values of G_i and P_i represent gains and power levels, respectively, for each of M different signal components, which may represent individual multipath components or gross signal components from one or more radiating sources, and K_i represents a finite number of constants or functions for each value of i. Note that G_i, P_i, and the individual K_i may be in logarithmic (e.g. dB) or absolute values. These constants or functions in the above equation may be dependent on distance (d) between transmitter and receiver where d may be the straight-line or actual reflected/diffracted distance of the main signal path between

the serving transmitter and receiver, 3-D environment, time of observation or observation interval, noise power, packet sizes, coding scheme, number of users, modulation type, interference, and for wireless networks, may include path loss, multipath delay, number of multipath components, angular spread, strength and angle of arrival of received signals, modulation bandwidth, and other physical, electrical and logical settings of particular equipment in the network, and the constants or functions may be calculated analytically, predicted for an initial guess, or solved using best fit methods between measured and predicted performance of actual networks in a site specific environment.

It is important to note that multipath delay, and its effect on network performance prediction and design, may be considered in many ways, as contemplated by this invention and as shown in Equation (1). First, multipath may be considered individually, whereby each multipath component is considered to arrive from each transmitting device, and the methods for modeling multipath are well known and explained in the prior art, and in numerous research works by Rappaport, et. al. from Virginia Tech. Alternatively, gross multipath effects may be modeled as having a worst-case delay (e.g. propagation distance, d) being approximated by the maximum, average, or median length of the specific building or 3-D environment in which the communication network is modeled. Alternatively, spatial considerations may be used by contemplating the antenna patterns of each transmitter or receiver, so that multipath which arrives only in the main beam of each wireless device is considered in the calculation of delay and in network performance in (1). Alternatively, only the strongest one or two or some finite number of transmitters may be considered for multipath propagation delays, whereby only a finite set of transmitters, such as those most closest to the receiver of interest, or those of a certain standard, frequency, or power setting, are considered to radiate multipath energy and produce RSSI values, and from that finite number of transmitters, only the strongest multipath, or the average, maximum, median, or largest few multipath components are considered in computation of delay. Alternatively, if only a finite number of transmitters are considered, methods described above, such as consideration of the physical environment to determine a gross multipath delay from each transmitter, or the use of a particular antenna pattern to determine most important multipath components, may be used to drive the model of multipath and its impact on network performance. Similar approaches may be used to model the received signal strength, RSSI in equation 1.

Note that the constants or functions of equation (1) may be assigned blindly for initial predictions, and then a specific network within the site-specific environment may be measured empirically so that a best-fit (using a minimum mean square error approach or some other well known method) may be used to assign values for the constants or functions in (1). Note that in (1), the distance (d) may be based on true physical distance from the 3-D site specific model of the environment, or may actually represent a relative distance ratio, where the physical distance between two points is referenced to a convenient close-in free space reference distance, as is customary for propagation predictions, and is taught in (Rappaport, "Wireless Communications, Principle & Practice, Prentice-Hall, 1996).

Propagation delay for network data is predicted for wired networks, where components are interconnected by wire (either fiber or metal wire) by dividing the distance traveled by the propagation speed of the electrical, electromagnetic or optical signals in the device, which are used to transmit the data. For instance, data in a fiber optic cable travels at a speed $2*10^8$ meters per second due to dielectric properties of the cable, which affect the photons in a fiber optic cable that are used to transmit the data. Such photons move at the speed of light in glass, which is less than the free space propagation speed. Thus, if the cable is 200 meters long the transmission delay is equal to $1*10^6$ seconds. By using the site-specific method of modeling the complete network within the present invention, it is possible for the user to simultaneously visualize the network as configured in the environment and see a display of delay and predicted or measured performance of delay within the cable within the 3-D environment. Additionally, using a tool tip mouse cursor or some other pointing means, or using a pull down menu, or by simply viewing the display device which the invention is implemented on, various network performance metrics, as well as stored data from the Bill of Materials and parameters of intrest may be visualized or stored.

Predicting the propagation delay for a wireless portion of a data communications network is more difficult than wired networks due to the fact that multiple transmitter sources, such as access points in a Bluetooth network, IEEE 802.11b, or wireless ATM network may be transmitting simultaneously. Furthermore, as mentioned previously, multipath interference can create echoes that may or may not be equalized depending on the specific network equipment used at the wireless receiver or transmitter. However, the same calculation model used for wired networks may be used, with the additional consideration of multipath delay terms, and propagation losses or gains, due to specific multipath components, as shown in Equation (1). This additional consideration of multipath delay is needed to account for the fact that wireless data does not always travel in a straight line, and that physical objects can diffract, reflect, absorb, and scatter radio energy. Thus, to calculate the transmission delay of a wireless link in a data communications network, the distance between the transmitter and the receiver is divided by the propagation speed ($3*10^8$ meters per second) of a wireless communications link and then added to the multipath delay introduced by the indirect paths taken from transmitter to receiver as is shown in equation 2.

$$T_p = \frac{d}{3*10^8\text{m/s}} + \tau_d \qquad (2)$$

Where T_p is the propagation delay in seconds, d is the distance between the transmitter and the receiver in meters, and τ_d is the multipath delay in seconds. Predicting the multipath delay is performed using well-known raytracing techniques or based on angle of arrival, or signal strength values, or by making estimated based on the physical model of the 3-D environment.

Transmission delay is directly calculated from the bandwidth of a connection using the number of bits transmitted. To calculate transmission delay, the number of transmitted bits is divided by the bandwidth. This calculation is identical for wired and wireless channels but must be performed separately for each network device. The formula is illustrated in equation 3.

$$T_t = \frac{\#\text{ of bits}}{BW} \tag{3}$$

Where T_t is the transmission delay time in seconds, # of bits are the number of bits in the transmission or packet and BW is the bandwidth of the network link in bits per seconds.

Processing delay must be calculated for each device separately within a network. Processing delay is the time required for a network device to process, store, and forward the data bits that are applied to a network device. Alternatively, processing delay may be the time required for a source to produce a meaningful data stream once it is instructed to do so. Processing delay is known to be zero for devices that do not perform any processing, such as passive network components like cables, antennas, or splitters. Processing time may depend on the packet size, protocol type, operating system, vendor, firmware, hardware, and software versions or configurations, and the type of device and the current computing load on the device. To predict the processing delay of any device it is necessary use a model that accounts for all of these effects. These models may be measured in the field, measured in a test facility, obtained from vendors, or derived from analysis or simulation.

Queuing delay is only applicable to devices that transmit data from multiple users or multiple connections. The queuing delay of a device is the amount of time a particular packet must wait for other traffic to be transmitted. It is difficult to predict the queuing delay of a particular connection because it depends on the amount of traffic handled by a particular device. For this reason, queuing delays can be predicted using a statistical random variable based on the expected performance of the device and/or the expected traffic load. Alternatively, average, median, best or worst case, or some other linear or nonlinear weighting of queuing delay times as defined by the device specifications, or as measured, simulated, or computed by analysis, may be used to calculate a predicted queuing delay time.

Packet latency, round-trip times and handoff delay times are all based on propagation, transmission, processing, and queuing delay times. To accurately predict packet latency and round trip time, the propagation, transmission, processing and queuing delay times must be summed for all network devices in a particular network link and adjusted using the particular traffic type, packet size, and protocol type. For instance, packet latency is the time required for a packet to travel from transmitter to receiver. To predict packet latency for a particular link the propagation, transmission, processing and queuing delay times must be calculated using the specific network connection, traffic type, and packet size for the one-way transmission of a packet.

Round trip times are calculated similarly, except for the transmission and reception of a packet and the return of the acknowledging packet. Thus, to predict the round trip time, the invention takes into account the original packet size and the size of the acknowledging packet as well as the effects of the specific network connection, protocol and traffic type on the propagation, transmission, processing and queuing delays.

Handoff delay times are based on the propagation, transmission, processing and queuing delays involved in two separate wireless access points coordinating the change of control of a wireless device from one access point to another. These delays result because the two access points must transmit data back and forth to successfully perform a handoff. Thus, the prediction of handoff delay time is similar to the prediction of the packet latency time between the two access points. To predict the handoff delay time, the invention calculates the propagation, transmission, processing and queuing delays for the link between the two access points. The invention then adjusts for the specific number of transmissions required and the size of the data, which must be sent to successfully perform a handoff.

When predicting bit error rates, the invention considers wired and wireless error rates. Wireless networks operate in much more hostile electrical environments than their wired counterparts and their interconnections are significantly more difficult to model and, until this invention, practical networks have not successfully been modeled using specific, accurate physical and electrical models of multiple transmitters, multiple interferers, noise sources, and network components within a 3-D site-specific environment. This invention uses 3-D site specific representations of the environment for specific network implementations that are able to consider both wired and wireless networks, and considers physical locations, electrical specifications and attributes of all radiating sources and their antenna systems in a real-world 3-D environmental model. Wireless networks are prone to data errors much more so than wired channels, due to the impact of multipath propagation, multiple transmitters, and noise, as described previously. The fact that radio propagation and noise is more random than for fixed wired networks must be considered for practical design, and is modeled in this invention. For wired channels, bit error rates are simply a measure of the electrical, optical and electromagnetic parameters of a connection and are predicted using a statistical random variable, such as a Gaussian or Poisson random distribution, or other sensible distribution or algorithm known now or in the future, and this random variable is overlaid about the average, median, or typical performance of the network component or network subsystem. The network device or subsystem may include a single wireless node, such as a router or switch, or a complete interconnection of various routers, hubs, switches, wireless access points, and wireless client/server devices that communicate with the network. The network may be wired, wireless, or a combination thereof.

Many performance metrics of a device or a network subsystem, such as Frame Error Rate, Bit Error Rate, or Packet Error Rate, as well as other performance parameters such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time may be either derived from a specification of the equipment, may be calculated analytically within the invention or inputted into the invention, or may be measured a priori in advance to using the invention. That is, specific parameters of operation, known as operating parameters or equipment parameters, such as those listed previously, can be either measured or predicted through equipment specifications provided by vendors. Alternatively, they may be measured in-situ by a user or research facility, for proper modeling and input into the invention. Alternatively, they may be calculated based on some known analytical model that contemplates interconnection of devices so that a performance model and operating parameters may be computed. The statistical random variable to model network performance within the invention can be dependant on the electrical, optical and electromagnetic characteristics of each device such as voltage levels, power levels, impedance,

and operating frequencies, or can be generated using a typical observed (measured) value for each network device. For instance, copper wire can be modeled as having a bit error rate of 1 error in 10^6 or 10^7 bits transmitted. Once measured and characterized a single initial time, a single component or a string of components within a network may be modeled repeatedly by the invention, so that network performance models.

Wireless performance parameters, however, are dependant on many more factors than wired bit error rates. For this reason, the invention predicts wireless bit error rates based on the environment, distance between transmitter and receiver, number and types of partitions obstructing the transmission, time, 3-D position, packet size, protocol type, modulation, radio frequency, radio frequency bandwidth, encoding method, error correction coding technique, multipath signal strengths and angle of arrival, and multipath delay. As a result, the calculation of the predicted bit error rate is performed using constants or functions to convert from previously measured or known channel and network equipment performance metrics to an expected bit error rate. A formulation for predicting the bit error rate, frame error rate or packet error rate directly for a data communications channel is shown in equation 4, and is identical to equation 1.

$$BER,\ PER,\ \text{or}\ FER = C_1[Ad + Bd^2 + C] + C_2[D(RSSI) + E(RSSI)^2 + F] + C_3\sum_{i=1}^{M}(G_iP_i + K_i) \tag{4}$$

where BER is bit error rate, FER is the frame error rate, PER is the packet error rate, d is the distance between a transmitter and a receiver. RSSI is the received signal strength intensity, which is the power level of the signal at the receiver. A, B, C, C_1, C_2, C_3, D, E, F, K_i, are constants or linear or non linear functions with different values depending on which of BER, FER, and PER is being calculated. The value M may denote particular number of multipath components from a particular transmitter, or may denote a combination of important multipath components from a collection of transmitters, where the term "important" is based on antenna pattern, physical environment distances, and other wireless propagation factors which are well known to one skilled in the art and which are explained within this disclosure. The each of M values of G_i and P_i represent gains and power levels, respectively, of different signal components, which may represent individual multipath components or gross signal components from one or more radiating sources, and may be in logarithmic or linear values of power. The variables G_i and P_i and each one of the M number of K_i values may be in logarithmic (e.g. dB) or absolute values. These constants in the above equation are dependant on distance (d) between transmitter and receiver where d may be the straight-line or actual reflected/diffracted distance of the main signal path between the serving transmitter and receiver. As explained in the text surrounding equation (1), distance may be straight-line distance, or may be modeled from the gross characteristics of the environment, such as the maximum, average, or median length of the 3-D environment. As with equation (1), equation (4) may consider the distance d as the actual physical distance, or as a relative distance referenced to a close-in reference.

Frame error rates, packet error rates and packet drop rates can all be calculated from bit error rates or predicted directly using the same method as for a bit error rate as described above or as modeled in equation 4. To perform these calculations the invention uses information stored in the site-specific Bill of Materials about the packet size, frame size and the protocol in use, and uses a site-specific propagation and interference modeling technique, such as that utilized in the SitePlanner product by Wireless Valley Communications, Inc.

In wireless networks, modeling the combined effects of all the various sources of errors is extremely difficult. Not only does modulation and specific error and source coding techniques impact the wireless network performance, but so does the impact of antennas, multipath, noise, voice over IP or wireless ATM concatenation methods, modem design of particular wireless modem makers, and the specific RF distribution system used to connect wired and wireless devices. The ability to model such varied effects can be done by allowing field measurement of specific in-situ network performance as explained earlier. By conducting a walk-through or a drive test whereby a mobile receiver is operated and network performance parameters are measured within the site-specific environment, it is then possible to determine best fits for particular modem manufacturers, applying concepts described in equation 1.

Bandwidth delay products can be calculated by the invention directly using information about any or all of the environment, three dimensional position, protocol type, multipath delay, packet sizes, radio frequency, radio frequency bandwidth, coding, number, strength and angle of arrival of multipath components, signal strength, transmission, propagation, processing and queuing delay, bit error rate, packet error rate, and frame error rates. Alternatively the invention can calculate the bandwidth delay product indirectly using previously predicted values. A bandwidth delay product is calculated by multiplying the bandwidth of a certain network device by the total delay introduced by that device. Thus, the formula is illustrated here in equation 5:

$$BWD = \frac{BW}{T_{net}} \tag{5}$$

Where BWD is the bandwidth delay product, BW is the bandwidth and T_{net} is the total delay introduced.

The invention uses statistical models of the consistency of data communications network hardware to predict packet jitter and quality of service (QoS). Both of these performance criterions are measures of the reliability of a network to provide consistent data arrival times. Thus, to calculate the QoS or jitter of a connection, the invention uses formulas which include any or all of the environment, three dimensional position, protocol type, multipath delay, packet sizes, radio frequency, radio frequency bandwidth, coding, number, strength and angle of arrival of multipath components, signal strength, transmission, propagation, processing and queuing delay, bit error rate, packet error rate, frame error rate, throughput, bandwidth, and bandwidth delay product. The formulas include constants or functions, which relate the above variables in general to the variation in the arrival time of data and in specific to the QoS and packet jitter of a connection. The present embodiment of the current invention uses equations (1) or (4) to determine QoS and packet jitter for a data communications network.

The preferred embodiment of the invention predictions consider the effects of not just the site specific, floor plan, building layout, terrain characteristics and RF characteris-

tics, but also the effects of the particular network hardware, firmware and software in the network. The invention allows the network to be modeled down to the settings and locations of the individual data communications devices, using the Bill of Materials discussed earlier. The prediction of network performance statistics takes these settings into account. This means that different transport level protocols (such as TCP or UDP), different protocol settings (such as packet and buffer sizes), the data bandwidth (in bits per second), physical layer transmission methods including modulation techniques (such as QPSK or FHSS), coding schemes (such as CCK or trellis codes), transport media (such as copper, fiber optic cable or wireless connections) and specific frequency bands are taken into account by the invention. These aspects are in addition to the consideration of the location and wireless specific criteria, which includes transmitter-receiver distance (T-R distance), the propagation environment, interference, path loss, number of users sharing the RF resources, multipath delay, the number of multipath components and their strengths and angle of arrival, the ratio of coherent to incoherent power, and the RF bandwidth (in Hz). All of these variables may produce results which may be mapped into the form of equation (1) or (4).

The predictions of the preferred form of the invention consider the characteristics of the data communications network users. Information such as the type of data communications traffic the users offer to the network, the number of users, and the usage patterns over time, are stored in a location specific manner in the invention. That is, points can be placed which represent individual users and the traffic offered by that user or areas in which the characteristics of a group or pool of users can be assigned. The invention takes these points and areas of user traffic into account when making predictions of network performance criterions. This means that if large numbers of users are found in an area covered by access points that are able to adapt to heavy usage, the invention is able to accurately predict the performance of these (or any other) conditions. This is only possible because of the accurate, location specific model of the data communication network. Additionally, since the preferred form of the invention tracks usage patterns of users over time, the resulting measurements may be used by a server processor to form table look-up values for the constants or functions of Equations (1) or (4). Different values of constants or functions for Equations (1) or (4) may be found to predict the performance of the network at different times of day. This is an important aspect of a data communication network prediction model because real networks have peak usage times and lulls in which usage is lower. By tracking the usage of a data communications network over time, the preferred form of the invention can determine if the network will have difficulties at certain times.

In a communications network, the capacity is always a scaled version of the theoretical maximum possible capacity, and the impact of various users, and their propagation characteristics, message sizes, as well as the network characteristics, all combine to bound or limit the capacity that an individual user sees on a network. Consider a network that has, as a bottleneck, a particular component or device which has a maximum rating of Tmax bits per second. This component bounds the maximum possible throughput of the network. Consider that capacity represents the capacity or throughput of a device or network (defined as T or Capacity), where T(x,y,z, t)=Tmax[γ], where y is a scaling factor that fuses many different, complicated physical, electrical, and logical conditions into a simple value that ranges between 0 and 1. When gamma is 0, there is no capacity. When gamma is 1, there is maximum capacity. Note that T is a function of 3-D positioning in the network, as well as a function of time. For a particular user, the goal of a network predictive model is to predict the capacity, as a function of 3-D position and as a function of time. Thus, T[x,y,z,t] will range between 0 and T_{max}.

The load put on to a data communications network impacts the capacity of an individual user. The number of users and the usage patterns of each user affect the capacity of each user in a data communications network. The preferred embodiment of the invention allows a network designer to see the effects of network loading on the important network statistics, by measuring the instantaneous traffic conditions with the measurement agents as described above. It is possible to determine in-situ capacity measurements through other means, such as observation from network equipment o reporting mechanisms built into hardware or software products. By forming a table look-up of the specific capacity results, as a function of 3-D site-specific location, as well as the time of day, the invention builds a measurement-based predictive model for capacity. These measurements may be used to form a model of capacity, as now presented.

The invention contemplates the fact that the scaling factor on capacity (or throughput), is a function of the instantaneous number of users of the network, the maximum number of simultaneous users of the network, the average and maximum packet size used by users of the network, and for many other factors that are modem or network or vendor or protocol specific. Also, in the case of a wireless network, the multipath propagation effects, the propagation distances between the user and the wireless access points, and the received signal levels are factors that limit capacity. In addition, constants or functions that fuse the impact of modulation, equalizations, impulse noise, and other factors, are used in the invention.

Thus, capacity or throughput of a network is modeled by

$$\text{Capacity} = C_1[Ad + Bd^2 + C] + C_2[D(RSSI) + E(RSSI)^2 + F] + C_3\sum_{i=1}^{M}(G_iP_i + K_i) \tag{6}$$

where the constants or functions of (6) take on similar properties as described for equations (1) and (4). Furthermore, the entire equation (6) may be scaled by K/Umax, where K is the instantaneous number of users on the network, and Umax denotes the maximum number of simultaneous users possible.

Handoff delay times are potential problems in wireless data communication networks. A handoff occurs in wireless data networks when a user moves out of range of one access point and into range of another access point. In this situation, the first access point must pass the responsibility of delivering data to the wireless user to the second access point. If the two access points are too far apart, there will not be enough time for a wireless data network user to be handed off from one access point to another and file transfers can fail. The invention predicts where handoffs will occur and the possibility of handoff failures due to incompatible network settings at two different access points by using site-specific time dependent measurements, and fitting them into a form of equation (1), (4) or (6). Then, a table look up method is used to determine prediction models for handoff times as a function of spatial positioning and time of day.

The concept of optimization is a key aspect of the invention. The preferred invention is highly effective at allowing one skilled in the art to quickly improve the performance of an existing data communications network by comparing measured performance parameters with predicted values that are derived and stored in the invention. The process of using measurements to improve predictions is called optimization and is illustrated in FIG. **6**, FIG. **7**, and FIG. **8**. The method for optimizing a network using just measurements is shown in FIG. **6**, just predictions in FIG. **7**, and a combination of measurements and predictions in FIG. **8**. The process of optimizing a data communications network is accomplished by comparing, through numerical, visual, or some other means, the predictions and measurements of performance criteria such as throughput, bandwidth, quality of service, bit error rate, packet error rate, frame error rate, dropped packet rate, packet latency, round trip time, propagation delay, transmission delay, processing delay, queuing delay, network capacity, packet jitter, bandwidth delay product and handoff delay time for various site-specific locations and particular times of day. By changing the hardware used in the network, or changing the locations of hardware or the configuration of that hardware, firmware, or software which controls each device within the network, one skilled in the art can improve the performance of the network. These performance improvements can implemented and viewed by repeating predictions of the performance criteria after site-specific equipment changes to the network have been made in the 3-D model of the network. Continuing this process allows one skilled in the art to optimize the performance of a network to achieve an efficient data communications network.

Using this information, the preferred embodiment of the invention can make recommendations for the areas of the network to upgrade or reconfigure. The invention can also use SNMP protocol communications or other protocols to actually implement these changes. That is, a network designer could identify problems in a data communications network through prediction, whereby the prediction of performance criteria of the data communications network is calculated using known measurement data and the configuration and expected performance of all data communications hardware in the data communications network. The predicted performance criterion is stored and displayed visually and numerically in a location specific, three-dimensional model of the environment. Then, the designer can use the invention to identify a solution to the problems that are apparent by viewing the prediction results, either by following the inventions recommendations for changes or making the designers own change. After simulating the predicted outcome, the network designer can then direct the invention to update all the relevant settings of the equipment with the changes the designer has just used in a prediction. The designer could then use the tool to measure the results of these changes using the measurement features of the invention.

While this invention has been described in terms of its preferred embodiments, those skilled in the art will recognize that the invention can be practiced with considerable variation within the scope of the appended claims.

What is claimed is:

1. A method for analyzing and adjusting a wireless communications network, comprising the steps of:

generating or using, with a computer or server, a computerized model of a wireless communications network within a physical space in which said wireless communications network is deployed, said computerized

model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics, or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said wireless communications network, said computerized model having modeled attributes for at least one each of said one or more components;

receiving, at said computer or server, measurement data from one or more measurement collectors or agents located in said physical space, said one or more measurement collectors or agents being the same or different from one or more of said one or more components used in said wireless communications network;

predicting, at said computer or server, one or more performance metrics for said wireless communications network, wherein predictions are made based on said modeled attributes for said at least one of said one or more components, and said measurement data from said one or more measurement collectors or agents; and

changing settings or configurations of at least one component of said wireless communications network based on instructions sent from said computer or server.

2. The method of claim **1** wherein said site specific representation is three dimensional.

3. The method of claim **1** wherein said data collection measurement collectors or agents are portable or fixed.

4. The method of claim **1** further comprising the step of affixing said measurement collectors or agents permanently within said physical space.

5. The method of claim **1** wherein said performance metric predicted in said predicting step is selected from the group consisting of throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, bit error rate, packet error rate, frame error rate, dropped packet rate, queuing delay, round trip time, capacity, signal level, interference level, bandwidth delay product, handoff delay time, signal-to-interface ratio, signal-to-noise ratio, physical equipment price, and cost information.

6. The method of claim **1** wherein said measurement data received in said receiving step obtained manually.

7. The method of claim **1** wherein said measurement data received in said receiving step obtained autonomously.

8. The method of claim **1** further comprising the step of storing said measurement data.

9. The method of claim **1** further comprising the step of updating said computerized model.

10. The method of claim **9** wherein said step of updating includes the steps of:

specifying components from a plurality of different modeled components which are to be used in said communications network, said modeled components including descriptions and attributes of a specific component; and

specifying locations within said physical space for a plurality of different components in said computerized model.

11. The method of claim **10** wherein said step of updating further includes the step of specifying an orientation for at least one component specified in said first specifying step at said location specified in said second specifying step.

12. The method of claim **1** wherein said computerized model identifies orientations of said components at said locations within said physical space and said predicting step utilizes said orientations.

13. The method of claim **1** wherein said computerized model includes one or more objects which create noise or

interference, said noise or interference being an attribute of said one or more objects which are factored in said predicting step.

14. The method of claim 1 wherein said one or more performance metrics predicted in said predicting step are predicted in a forward direction in said wireless communication network.

15. The method of claim 1 wherein said one or more performance metrics predicted in said predicting step are predicted in a reverse direction in said wireless communication network.

16. The method of claim 1 further comprising the step of specifying data transfer protocol, and wherein said predicting step uses a specified data transfer protocol as a factor in predicting said one or more performance metrics.

17. The method of claim 1 further comprising the step of specifying a network loading for said wireless communications network, and wherein said predicting step uses a specified network loading in predicting said one or more performance metrics.

18. The method of claim 1 further comprising the step of storing or visualizing data representing comparisons of measurements with predictions.

19. The method of claim 1 further comprising the step of storing or visualizing data representing either or both logical connections of network components or physical locations of network components.

20. A system or apparatus for analyzing and adjusting a wireless communications network, comprising:

a computer or server for generating or using a computerized model of a wireless communications network positioned within a physical space, said computerized model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics, or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said wireless communications network, said computerized model having modeled attributes for at least one of said one or more components;

one or more measurement collectors or agents operating or operational within said physical space which send measurement data to said computer or server, said computer or server predicting one or more performance metrics for said wireless communications network based on said measurement data and said modeled attributes for said at least one of said one or more components, and said computer or server can send instructions to one or more components of said wireless communications network which cause settings or configurations of at least one component to be changed.

21. The system or apparatus of claim 20 wherein said site specific representation is three dimensional.

22. The system or apparatus of claim 20 wherein said measurement collectors or agents are portable or fixed.

23. The system or apparatus of claim 20 wherein said measurement collectors or agents are permanently affixed at within said physical space.

24. The system or apparatus of claim 20 wherein said performance metric predicted by said computer or server is selected from the group consisting of throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, bit error rate, packet error rate, frame error rate, dropped packet rate, queuing delay, round trip time, capacity, signal level, interference level, bandwidth delay product, handoff delay time, signal-to-interface ratio, signal-to-noise ratio, physical equipment price, cost information.

25. The system or apparatus of claim 20 further comprising a storage device for storing said measurement data.

26. The system or apparatus of claim 20 wherein said computerized model is stored on at least one server, wherein said at least one server is the same or different from said computer or server.

27. The system or apparatus of claim 26 wherein said computerized model is stored on a plurality of servers, and said plurality of servers can communicate with each other.

28. The system or apparatus of claim 27 wherein said plurality of servers have a heirarchical relationship to one another.

29. The system or apparatus of claim 26 further comprising at least one portable client device, said at least one portable client device can communicate with said at least one server.

30. The system or apparatus of claim 28 wherein said system includes a plurality of portable client devices.

31. The system or apparatus of claim 20 further comprising a storage medium or display for, respectively, storing or visualizing data representing comparisons of measurements with predictions.

32. The system or apparatus of claim 20 further comprising a storage medium or display for, respectively, storing or visualizing either or both logical connections of network components or physical locations of network components.

33. A method for analyzing and adjusting a wireless communications network, comprising the steps of:

generating or using, with a computer or server, a computerized model of a wireless communications network within a physical space in which said communications network is deployed, said computerized model providing a site specific representation of one or more of a floor plan, building model, terrain characteristics, or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said wireless communications network, said computerized model having modeled attributes for at least one of said one or more components;

downloading or inputting files of measurement data to said computer or server, where said measurement data is obtained from said physical space or from said wireless communications network;

predicting or providing a one or more performance metrics for said wireless communications network based on said measurement data and said modeled attributes for said at least one of said one or more components; and

changing settings or configurations of at least one component of said wireless communications network based on instructions sent from said computer or server.

34. The method of claim 33 wherein said measurement data is obtained from measurement collectors or agents that are either portable or fixed.

35. The method of claim 33 further comprising the step of storing or visualizing data representing comparisons of measurements with predictions.

36. The method of claim 33 further comprising the step of storing or visualizing data representing either or both logical connections of network components or physical locations of network components.

37. A site specific method for analyzing and adjusting a communications network, comprising the steps of:

generating or using, with a computer or server, a computerized model of a communications network positioned within a physical space, said computerized model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said communications network, said computerized model having modeled attributes for at least one of said one or more components

receiving, at said computer or server, measurement data from one or more measurement collectors or agents located in said physical space, said one or more measurement collectors or agents being the same or different from one or more of said one or more components used in said communications network;

predicting, using said computer or server, one or more performance metrics for said communications network, wherein predictions are made based on said measurement data and said modeled attributes for at least one of said one or more components;

changing settings or configurations of at least one component of said communications network based on instructions sent from said computer or server.

38. The method of claim **37** wherein said site specific representation is three dimensional.

39. The method of claim **37** wherein said measurement collectors or agents portable or fixed.

40. The method of claim **37** further comprising the step of affixing said measurement collectors or agents permanently within said physical space.

41. The method of claim **37** wherein said one or more performance metrics predicted in said predicting step are selected from the group consisting of one or more performance metrics are selected from radio signal strength intensity, connectivity, network throughput, bit error rate, frame error rate, signal-to-interference ratio, signal-to-noise ratio, frame resolution per second, traffic, capacity, signal strength, throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, server identification parameters, transmitter identification parameters, best server locations, transmitter location parameters, billing information, network performance parameters, C/I, C/N, body loss, height above floor, height above ground, noise figure, secure coverage locations, propagation loss factors, angle of arrival, multipath components, multipath parameters, antenna gains, noise level reflectivity, surface roughness, path loss models, attenuation factors, throughput performance metrics, packet error rate, round trip time, dropped packet rate, queuing delay, signal level, interference level, quality of service, bandwidth delay product, handoff delay time, signal loss, data loss, number of users serviced, user density, locations of adequate coverage, handoff locations or zones, locations of adequate throughput, E_c/I_o, system performance parameters, equipment price, maintenance and cost information, user class or subclass, user type, position location, all in either absolute or relative terms.

42. The method of claim **37** wherein said measurement data received in said receiving step is obtained manually.

43. The method of claim **37** wherein said measurement data received in said receiving step is obtained autonomously.

44. The method of claim **37** further comprising the step of storing said measurement data.

45. The method of claim **37** further comprising the step of updating said computerized model.

46. The method of claim **45** wherein said step of updating includes the steps of:

specifying components from a plurality of different modeled components which are to be used in said communications network, said modeled components including descriptions and attributes of a specific component; and

specifying locations within said space for a plurality of different components in said computerized model.

47. The method of claim **46** wherein said step of updating further includes the step of specifying an orientation for at least one component specified in said specifying components step at said location specified in said specifying locations step.

48. The method of claim **37** wherein said computerized model identifies orientations of one or more of said one or more components at said locations within said physical space and said predicting step utilizes said orientations.

49. The method of claim **37** wherein said computerized model includes one or more objects which create noise or interference, said noise or interference being an attribute of said one or more objects which are factored in said predicting step.

50. The method of claim **37** wherein said one or more performance metrics predicted in said predicting step are predicted in a forward direction in said communication network.

51. The method of claim **37** wherein said one or more performance metrics predicted in said predicting step are predicted in a reverse direction in said communication network.

52. The method of claim **37** further comprising the step of specifying data transfer protocol, and wherein said predicting step uses a specified data transfer protocol as a factor in predicting said performance metric.

53. The method of claim **37** further comprising the step of specifying a network loading for said communications network, and wherein said predicting step uses a specified network loading in predicting said one or more performance metrics.

54. The method of claim **37** further comprising the step of storing or visualizing data representing comparisons of measurements with predictions.

55. The method of claim **37** further comprising the step of storing or visualizing data representing either or both logical connections of network components or physical locations of network components.

56. A site specific system or apparatus for analyzing and adjusting a communications network, comprising:

a computer or server for generating or using a computerized model of a communications network positioned within a physical space, said computerized model providing a site specific representation of one or more of a floor plan, building layout, terrain characteristics or RF characteristics, said computerized model identifying locations within said physical space of one or more components used in said communications network, said computerized model having modeled attributes for at least one of said one or more components;

one or more measurement collectors or agents positioned within said physical space which obtain and send measurement data to said computer or server, said computer or server predicting one or more performance metrics for said communications network based on said measurement data and said modeled attributes for said at least one of said one or more components, and said

computer or server can send instructions to one or more components of said communications network which cause settings or configurations of at least one component to be changed.

57. The system or apparatus of claim **56** wherein said site specific representation is three dimensional.

58. The system or apparatus of claim **56** wherein said measurement collectors or agents are portable or fixed.

59. The system or apparatus of claim **56** wherein said measurement collectors or agents are permanently affixed at locations within said physical space.

60. The system or apparatus of claim **56** wherein said one or more performance metrics selected from the group consisting of one or more performance metrics are selected from radio signal strength intensity, connectivity, network throughput, bit error rate, frame error rate, signal-to-interference ratio, signal-to-noise ratio, frame resolution per second, traffic, capacity, signal strength, throughput, error rates, packet latency, packet jitter, symbol jitter, quality of service, security, coverage area, bandwidth, server identification parameters, transmitter identification parameters, best server locations, transmitter location parameters, billing information, network performance parameters, C/I, C/N, body loss, height above floor, height above ground, noise figure, secure coverage locations, propagation loss factors, angle of arrival, multipath components, multipath parameters, antenna gains, noise level reflectivity, surface roughness, path loss models, attenuation factors, throughput performance metrics, packet error rate, round trip time, dropped packet rate, queuing delay, signal level, interference level, quality of service, bandwidth delay product, handoff delay time, signal loss, data loss, number of users serviced, user density, locations of adequate coverage, handoff locations or zones, locations of adequate throughput, E_c/I_0, system performance parameters, equipment price, maintenance and cost information, user class or subclass, user type, position location, all in either absolute or relative terms.

61. The system or apparatus of claim **56** further comprising a storage device for storing said measurement data.

62. The system or apparatus of claim **56** wherein said computerized model is stored on at least one server which may be the same or different from said computer or server.

63. The system or apparatus of claim **62** wherein said computerized model is stored on a plurality of servers, wherein said plurality of servers can communicate with each other.

64. The system or apparatus of claim **63** wherein said plurality of servers have a heirarchical relationship to one another.

65. The system or apparatus of claim **62** further comprising at least one portable client device that can communicate with said at least one server.

66. The system or apparatus of claim **64** wherein said system includes a plurality of portable client devices.

67. The system or apparatus of claim **56** further comprising a storage medium or display for, respectively, storing or visualizing data representing comparisons of measurements with predictions.

68. The system or apparatus of claim **56** further comprising a storage medium or display for, respectively, storing or visualizing either or both logical connections of network components or physical locations of network components.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,973,622 B1
APPLICATION NO. : 09/668145
DATED : December 6, 2005
INVENTOR(S) : Rappaport et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 30, line 7 change "each of" to --of--

Column 30, line 38 change "interface" to --interference --

Column 30, line 42 insert "is" after "step"

Column 30, line 44 insert "is" after "step"

Column 32, line 2 change "interface" to --interference--

Column 32, line 21 insert "or apparatus" after "system"

Column 32, line 48 delete "a"

Column 33, lines 36, 37 delete "one or more performance metrics are selected from"

Column 35, line 14 delete "one or more performance metrics are selected from"

Signed and Sealed this

Fifth day of September, 2006

Jon W. Dudas

JON W. DUDAS
Director of the United States Patent and Trademark Office

EXHIBIT 2

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SYMBOL TECHNOLOGIES, INC., a Delaware Corporation, and WIRELESS VALLEY COMMUNICATIONS, INC., a Delaware Corporation, Plaintiffs and Counter-Defendants, v. ARUBA NETWORKS, INC., a Delaware corporation, Defendant and Counter-Claimant.	C. A. No. 07-519-JJF DEMAND FOR JURY TRIAL

ANSWER AND COUNTERCLAIMS

INTRODUCTION AND SUMMARY

Sometimes, when companies are losing in the marketplace, they sue – hoping that they can persuade jurors to overrule the verdict of the market. This lawsuit, filed by Symbol Technologies, Inc., and Wireless Valley Communications, Inc. (both wholly owned subsidiaries of global behemoth Motorola, Inc.), is that type of case.

Aruba Networks, Inc., was founded in 2002. In early 2003, it announced major advancements in wireless LAN technologies. Aruba's advancements allowed corporations and other enterprises to lock the air against intruders, enable high-speed mobile firewalls that follow users, and construct self-calibrating Wi-Fi networks. Aruba's innovations were met with widespread acclaim – and, almost immediately, Symbol's strong interest.

Recognizing the superiority of Aruba's technologies, Symbol tried to get access to them by buying Aruba. Throughout the first half of 2003, in the course of discussions initiated by Symbol, Aruba gave Symbol essentially unfettered access to Aruba's products – the way they were designed, built, tested, and made – and to Aruba's business and marketing strategies and

plans. Although Symbol was very interested in acquiring Aruba and its technologies, ultimately the parties were not able to agree on the complete terms of a transaction.

In the years since Symbol's close inspection of Aruba, Aruba has continued to receive widespread recognition as a fast-growing technology innovator. In 2003, Aruba won the prestigious Comdex Best in Show Award. In 2005, it won the Techworld.com Wireless Security Product of the Year Award. In 2007, Aruba won the Best Wireless Broadband Security Innovation Award at the Wireless Broadband Innovations Awards, as well as the Best of Interop 2007: Wireless & Mobility Category. These are just a few of the many awards it has won since its founding in 2002.

Aruba's technological innovations have paralleled its success in the marketplace. For example, according to a published report by Dell'Oro Group, Aruba's share of the enterprise wireless LAN market rose to greater than 10% in the second quarter of 2007 from roughly 5% in the same period of 2005. During the same period, Motorola's Symbol unit lost market share, and Aruba displaced Motorola/Symbol as the world's second largest enterprise wireless LAN supplier.

On the eve of Aruba's quarterly earnings announcement a month or so ago, in which Aruba announced a significant increase in revenue, Motorola's subsidiaries, Symbol and Wireless Valley, filed this lawsuit – on patents that began issuing in 2003. The next morning, coincident with Aruba's earnings release and only hours in advance of Aruba's conference call, Motorola issued a press release announcing the filing of the suit. The complaint fails to explain why the plaintiffs:

- waited for four years after Symbol's close inspection of Aruba's technology and business to sue;
- sued with no prior notice to Aruba; and
- chose to bring this lawsuit on the eve of Aruba's earnings announcement.

That explanation can be found in Aruba's success in the marketplace.

PARTIES

1. Aruba admits that in Securities and Exchange Commission filings Motorola, Inc., has described Symbol as a wholly owned subsidiary. Aruba is without knowledge or information sufficient to form a belief as to the truth of the remaining allegations of Paragraph 1 of the Complaint and therefore denies those allegations.

2. Aruba admits that in Securities and Exchange Commission filings Motorola, Inc., has described Wireless Valley as a wholly owned subsidiary. Aruba is without knowledge or information sufficient to form a belief as to the truth of the remaining allegations of Paragraph 2 of the Complaint and therefore denies those allegations.

3. Aruba admits that it is a Delaware corporation with a principal place of business at 1322 Crossman Avenue, Sunnyvale, CA 94089-1113, and that, for purposes of this action, The Corporation Trust Company is its registered agent for service of process in Delaware. The Complaint does not make clear what plaintiffs mean in the third sentence of Paragraph 3 of the Complaint, and Aruba therefore denies those allegations.

JURISDICTION AND VENUE

4. Aruba admits that this action purports to arise under the Patent Laws of the United States, Title 35, United States Code, but denies any wrongdoing or liability. Aruba further admits that this Court has subject matter jurisdiction over the allegations in the Complaint under 28 U.S.C. §§ 1331 and 1338(a).

5. Aruba does not dispute that for purposes of this action venue is proper in this judicial district.

6. Aruba admits that it is subject to personal jurisdiction in this judicial district because Aruba is a Delaware corporation with an agent for service of process in Delaware. Except as expressly admitted, Aruba denies the allegations of Paragraph 6 of the Complaint.

THE ASSERTED PATENTS – DENIAL OF INFRINGEMENT

7. Aruba admits that U.S. Patent No. 7,173,922 ("the '922 patent"), entitled "Multiple Wireless Local Area Networks Occupying Overlapping Physical Spaces," purports to

have issued on February 6, 2007, but denies that this patent was duly and legally issued. Aruba admits that a document that purports to be a copy of the '922 patent is attached to the Complaint as Exhibit A, but Aruba lacks knowledge that it is a true and correct copy and therefore denies the remaining allegations of Paragraph 7 of the Complaint.

8. Aruba admits that U.S. Patent No. 7,173,923 ("the '923 patent"), entitled "Security In Multiple Wireless Local Area Networks," purports to have issued on February 6, 2007, but denies that this patent was duly and legally issued. Aruba admits that a document that purports to be a copy of the '923 patent is attached to the Complaint as Exhibit B, but Aruba lacks knowledge that it is a true and correct copy and therefore denies the remaining allegations of Paragraph 8 of the Complaint.

9. Aruba is without knowledge or information sufficient to form a belief as to the truth of the allegations of Paragraph 9 of the Complaint and therefore denies those allegations.

10. Aruba admits that U.S. Patent No. 6,625,454 ("the '454 patent"), entitled "Method and System for Designing or Deploying a Communications Network Which Considers Frequency Dependent Effects," purports to have issued on September 23, 2003, but denies that this patent was duly and legally issued. Aruba admits that a document that purports to be a copy of the '454 patent is attached to the Complaint as Exhibit C, but Aruba lacks knowledge that it is a true and correct copy and therefore denies the remaining allegations of Paragraph 10 of the Complaint.

11. Aruba admits that U.S. Patent No. 6,973,622 ("the '622 patent"), entitled "System and Method for Design, Tracking, Measurement, Prediction and Optimization of Data Communication Networks," purports to have issued on December 6, 2005, but denies that this patent was duly and legally issued. Aruba admits that a document that purports to be a copy of the '622 patent is attached to the Complaint as Exhibit D, but Aruba lacks knowledge that it is a true and correct copy and therefore denies the remaining allegations of Paragraph 11 of the Complaint.

12. Aruba is without knowledge or information sufficient to form a belief as to the truth of the allegations of Paragraph 12 of the Complaint and therefore denies those allegations.

FIRST ASSERTED CLAIM – '922 PATENT

13. Aruba incorporates its responses to the allegations of Paragraphs 1-12 of the Complaint here.

14. Aruba denies the allegations of Paragraph 14 of the Complaint.

15. Aruba denies the allegations of Paragraph 15 of the Complaint.

16. Aruba denies the allegations of Paragraph 16 of the Complaint.

17. Aruba denies the allegations of Paragraph 17 of the Complaint.

18. Aruba denies the allegations of Paragraph 18 of the Complaint.

SECOND ASSERTED CLAIM – '923 PATENT

19. Aruba incorporates its responses to the allegations of Paragraphs 1-12 of the Complaint here.

20. Aruba denies the allegations of Paragraph 20 of the Complaint.

21. Aruba denies the allegations of Paragraph 21 of the Complaint.

22. Aruba denies the allegations of Paragraph 22 of the Complaint.

23. Aruba denies the allegations of Paragraph 23 of the Complaint.

24. Aruba denies the allegations of Paragraph 24 of the Complaint.

THIRD ASSERTED CLAIM – '454 PATENT

25. Aruba incorporates its responses to the allegations of Paragraphs 1-12 of the Complaint here.

26. Aruba denies the allegations of Paragraph 26 of the Complaint.

27. Aruba denies the allegations of Paragraph 27 of the Complaint.

28. Aruba denies the allegations of Paragraph 28 of the Complaint.

29. Aruba denies the allegations of Paragraph 29 of the Complaint.

30. Aruba denies the allegations of Paragraph 30 of the Complaint.

FOURTH ASSERTED CLAIM – '622 PATENT

31. Aruba incorporates its responses to the allegations of Paragraphs 1-12 of the Complaint here.

32. Aruba denies the allegations of Paragraph 32 of the Complaint.

33. Aruba denies the allegations of Paragraph 33 of the Complaint.

34. Aruba denies the allegations of Paragraph 34 of the Complaint.

35. Aruba denies the allegations of Paragraph 35 of the Complaint.

36. Aruba denies the allegations of Paragraph 36 of the Complaint.

SEPARATE DEFENSES

37. In addition to the defenses described below, Aruba expressly reserves the right to allege additional defenses as they become known through the course of discovery.

FIRST DEFENSE – NON-INFRINGEMENT

38. Aruba has not infringed, directly or indirectly, any valid asserted claim of the '922, '923, '454, or '622 patents (collectively "patents-in-suit").

SECOND DEFENSE – INVALIDITY UNDER §§ 102 AND 103

39. Aruba is informed and believes, and on that basis alleges, that each of asserted claims of each of the patents-in-suit is invalid for failure to meet the conditions of patentability set forth in 35 U.S.C. §§ 102 and 103, because the alleged inventions thereof are anticipated by, taught by, suggested by, and/or obvious in view of the prior art, and no claim of any of the patents-in-suit can be validly construed to cover any Aruba product or method.

THIRD DEFENSE – INVALIDITY UNDER § 112

40. Aruba is informed and believes, and on that basis alleges, that each of the asserted claims of each of the patents-in-suit are invalid for failure to comply with 35 U.S.C. § 112.

FOURTH DEFENSE – INVALIDITY UNDER § 101

41. Aruba is informed and believes, and on that basis alleges, that each of the asserted process claims of each of the patents-in-suit are invalid for failure to comply with 35 U.S.C. § 101.

FIFTH DEFENSE – EQUITABLE ESTOPPEL

42. The relief sought by Symbol is barred in whole or in part by the doctrine of equitable estoppel.

43. Without limiting the generality of the above allegations, Symbol asserts infringement because "Aruba designs, manufactures, and sells in the United States wireless switches (which it calls mobility controllers), access points, management servers, and related software for use in connection with WLANs, as well as software for designing, planning, configuring, monitoring, managing, and optimizing WLANs." (Complaint ¶ 3.)

44. Symbol has known this since at least early 2003, when it told Aruba that it (Symbol) wanted to purchase Aruba and spent months trying to convince Aruba to allow Symbol to purchase it. In the course of those efforts, Symbol sent senior engineers – ***including the individual named as the inventor on the '922 and '923 patents-in-suit*** – to Aruba to learn, in copious detail, about Aruba's products. Those discussions lasted for several months. During them, Aruba provided Symbol with extensive access to information about Aruba's products, the way they were designed and built, the way they worked, Aruba's plans for manufacturing and selling them, and Aruba's plans for future products.

45. Although Symbol was very interested in acquiring Aruba and its technologies, ultimately the parties were not able to agree on the complete terms of a transaction.

46. At the time that Symbol was trying to convince Aruba to be purchased, Symbol's '922 and '923 patent applications were no longer confidential – they had been published two years earlier, in 2001. Although those Symbol patent applications were no longer confidential, at no point during Symbol's efforts to convince Aruba did Symbol advise or suggest that if Aruba did not agree to a transaction, Symbol would later assert those pending patents against it. At no point during Symbol's efforts to convince Aruba did Symbol advise or suggest that Symbol had already invented the technology that Aruba had. In fact, quite the contrary: Symbol was very impressed with Aruba's technologies, and told Aruba that it (Symbol) thought those technologies to be superior to, and different from, Symbol's.

47. Symbol's failures and omissions were particularly egregious given that the putative named inventor on those patent applications was an integral part of the senior engineering team that was handpicked by Symbol to learn about Aruba's products – the products that Symbol now says infringes the '922 and '923 patents, and have (according to Symbol) done so since 2003.

48. Symbol's failures and omissions led Aruba reasonably to infer that Symbol did not intend to enforce any patent rights, including the then-pending '922 and '923 patent applications if they issued as patents, against Aruba. As far as Aruba understood from Symbol's conduct and silence, the parties were going to go compete in the market and let the marketplace decide which technologies and businesses were superior.

49. Since its discussions with Symbol ended in 2003, Aruba has successfully continued its efforts to invest and to innovate. It has established customer relationships based on the products that it disclosed to Symbol during the discussions in 2003. It has spent tens of millions of dollars growing its business based on the products that it disclosed to Symbol in 2003. It has attracted key executive, engineering, finance, and sales personnel based on the success of the products that it disclosed to Symbol in 2003. In these and other ways, it would materially prejudice Aruba for Symbol to be allowed to proceed with its claims.

SIXTH DEFENSE – LACHES

50. The relief sought by Symbol and Wireless Valley is barred in whole or in part by the doctrine of laches. Aruba incorporates the allegations of Paragraphs 43 through 49 here.

51. Without limiting the generality of the above allegations, as noted above, Symbol and Wireless Valley assert infringement because "Aruba designs, manufactures, and sells in the United States wireless switches (which it calls mobility controllers), access points, management servers, and related software for use in connection with WLANs, as well as software for designing, planning, configuring, monitoring, managing, and optimizing WLANs." (Complaint ¶ 3.) Even leaving aside the 2003 discussions between Symbol and Aruba, Symbol and Wireless Valley have known of Aruba and its activities for years.

52. In May 2003, for example, industry press reported, in an article that quotes both Aruba and Symbol officials, that "Start-ups and old timers in the networking and wireless worlds are flocking to the wireless switching market. The list includes . . . Aruba Wireless Networks, . . . Symbol Technologies, [and others]." There are many other such press and other such examples. Accordingly, Symbol and Wireless Valley knew or reasonably should have known of the activities now alleged by Symbol and Wireless Valley to infringe the patents-in-suit long ago.

53. In fact, this is true ***even according to Symbol and Wireless Valley***. In an August 2007 industry article about this lawsuit, Symbol's current General Counsel is described as stating that "[a]ll of Aruba's WLAN switch, site planning and radio-frequency management and monitoring products infringe the patents, ***and they have since the company began selling its first products.***" Nevertheless, Symbol and Wireless Valley delayed in bringing this suit until August 2007, on patents that first started issuing in September 2003 – waiting while Aruba invested tens of millions of dollars in designing and testing its products, developing customer relationships, and building its business. Symbol's and Wireless Valley's delay was unreasonable, inexcusable, and prejudicial to Aruba, and Symbol's and Wireless Valley's claims are barred as a result.

SEVENTH DEFENSE – INEQUITABLE CONDUCT ('922 AND '923 PATENTS)

54. Aruba is informed and believes, and on that basis alleges, that individuals charged with a duty of candor on behalf of Symbol failed, with an intent to deceive, to properly disclose to the U.S. Patent and Trademark Office information material to the patentablity of the '922 and '923 patents and failed to follow the requirements of the Manual of Patent Examiners Procedure necessary to have this information considered by the U.S. Patent and Trademark Office.

55. This information includes, but is not limited to, the existence of co-pending U.S. application no. 09/457,624 (the "'624 application"), filed on December 8, 1999. At the time of filing, the '624 application was purportedly owned by Proxim, Inc., and described and claimed subject matter that, to a reasonable patent examiner, would have been material to the

patentability of the '922 and '923 patents. On or before October 1, 2004, Proxim assigned its rights in the '624 application to Symbol, so Symbol had knowledge of the contents of the '624 application at least as of the date of the assignment and likely before that. Despite knowing of the highly material contents of the '624 application, individuals charged with a duty of candor on behalf of Symbol failed to disclose the existence of the '624 application to the patent examiner responsible for the examination of the applications that resulted in the '922 and '923 patents. The patent examiner responsible for those applications would have found the 624 application material because, among other things, the examiner would have then been able to determine whether to issue a provisional obviousness-type double patenting rejection.

56. In light of the above, the '922 and '923 patents are not enforceable due to inequitable conduct.

EIGHTH DEFENSE – INEQUITABLE CONDUCT ('454 PATENT)

57. Aruba is informed and believes, and on that basis alleges, that individuals charged with a duty of candor on behalf of Wireless Valley failed, with an intent to deceive, to properly disclose to the U.S. Patent and Trademark Office information material to the patentablity of the '454 patent and failed to follow the requirements of the Manual of Patent Examiners Procedure necessary to have this information considered by the U.S. Patent and Trademark Office.

58. This information includes, but is not limited to, the following: (i) information and publications relating to SMT Plus, a software tool developed, at least in part, by Theodore Rappaport and Roger Skidmore, and licensed to over twenty entities more than one year prior to the filing date of the '454 patent; (ii) the following publications, which the named inventors and/or prosecuting patent attorneys knew were never considered by the U.S. Patent and Trademark Office due to Wireless Valley's late submission of an Information Disclosure Statement in violation of U.S. Patent and Trademark Office rules: R.P. Torres, et al., *CINDOOR: An Engineering Tool for Planning and Design of Wireless Systems in Enclosed Spaces*, IEEE Antennas and Propagation Magazine, Vol. 41, No. 4 (Aug 1999); M. Panjwani et al., *Interactive Computation of Coverage Regions for Wireless Communication in Multifloored*

Indoor Environments, IEEE Journal on Selected Areas in Communications, Vol. 14, No. 3 (Apr. 1996); U.S. Patent No. 5,491,644; R. Skidmore et al., *A Comprehensive In-Building and Microcellular Wireless Communication System Design Tool*, The Bradley Department of Electrical Engineering, MPRG-TR-97-13 (Jun. 1997); U.S. Patent No. 5,987,328; Robert Morrow et al., *Getting In*, Wireless Review, Vol. 17, No. 5 (Mar. 1, 2000); (iii) S. Fortune, et al., *WISE Design of Indoor Wireless Systems: Practical Computation and Optimization*, IEEE Computational Science & Engineering, at pp. 58-68 (Spring, 1995), at pp. 58-68 (mentioned in the background section of U.S. Patent No. 7,055,107, another Rappaport and Skidmore patent filed just days before the filing date of the '454 patent by the same attorneys that filed the '454 patent); and (iv) the following additional publications authored, at least in part, by Theodore Rappaport: Theodore Rappaport et al., *Curriculum Innovation for Simulation and Design of Wireless Communications Systems*, ASEE Annual Conference Proceedings (1996); Keith Blankenship et al., *Measurements and Simulation of Radio Frequency Impulsive Noise in Hospitals and Clinics*, Proceedings of the 47th IEEE Vehicular Technology (1997); Donna Krizman et al., *Modeling and Simulation of Narrowband Phase from the Wideband Channel Impulse Response*, Proceedings of the 47th IEEE Vehicular Technology (1997); Hanif Sherali et al., *Optimal Location of Transmitters for Micro-Cellular Radio Communication System Design*, IEEE Journal on Selected Areas in Communications, Vol. 14, No. 4 (May 1996); Lynn Abbott et al., *Interactive Computation of Coverage Regions for Indoor Wireless Communication*, Proceedings of SPIE - The International Society for Optical Engineering (1995); Jorgen Andersen et al., *Propagation Measurements and Models for Wireless Communications Channels*, IEEE Communications Magazine, Vol. 33, No. 1 (Jan. 1995); M. Panjwani et al., *An Interactive System for Visualizing Wireless Communication Coverage within Buildings*, Wireless Personal Communications, Virginia Tech's 4th Symposium (June 1-3, 1994); and Theodore Rappaport, *Sponsored Research in Radio Propagation and System Design Final Report* (Sep. 26th, 1997).

59. In light of the above, the '454 patent is not enforceable due to inequitable conduct.

NINTH DEFENSE – INEQUITABLE CONDUCT ('622 PATENT)

60. Aruba is informed and believes, and on that basis alleges, that individuals charged with a duty of candor on behalf of Wireless Valley failed, with an intent to deceive, to properly disclose to the U.S. Patent and Trademark Office information material to the patentablity of the '622 patent and failed to follow the requirements of the Manual of Patent Examining Procedure necessary to have this information considered by the U.S. Patent and Trademark Office, and made false and misleading statements to the U.S. Patent and Trademark Office during the prosecution of the '622 patent.

61. This information includes, but is not limited to, U.S. Patent No. 6,505,045 (the "'045 patent"). At the relevant time, the Manual of Patent Examining Procedure stated that "It is desirable to avoid the submission of long lists of documents if it can be avoided. Eliminate clearly irrelevant and marginally pertinent cumulative information. ***If a long list is submitted, highlight those documents which*** have been specifically brought to applicant's attention and/or ***are known to be of most significance.***" Despite the highly material disclosure of the '045 patent, individuals charged with a duty of candor on behalf of Wireless Valley cited the reference by including it as reference number 98 in an Information Disclosure Statement that included a long list of many complex separate documents, all submitted at the same time, to increase the chance that the '045 patent would be overlooked by the patent examiner, and stated that the '045 patent was "only cited as constituting related art of which the applicant is aware" and specifically disclaimed that "the references are relevant or material to the claims."

62. In light of the above, the '622 patent is not enforceable due to inequitable conduct.

TENTH DEFENSE – UNCLEAN HANDS

63. Aruba incorporates the allegations of Paragraphs 42 through 62 here.

64. By reason of the acts alleged above, as incorporated, each of Symbol and Wireless Valley are barred from recovery for any asserted infringement of the patents-in-suit by the equitable doctrine of unclean hands.

ELEVENTH DEFENSE – PROSECUTION HISTORY ESTOPPEL

65. Symbol and Wireless are estopped from construing the asserted claims of the patents-in-suit to read on Symbol's products or processes by reasons of statements made to the U.S. Patent and Trademark Office during the prosecution of the applications that led to the issuance of the patents-in-suit.

TWELFTH DEFENSE – PLAINTIFFS' FAILURE TO GIVE NOTICE

66. To the extent Symbol and Wireless Valley seek damages for alleged infringement prior to its giving actual or constructive notice of the patents-in-suit patent to Aruba, the relief they seek is barred by 35 U.S.C. § 287.

DEMAND FOR A JURY TRIAL

67. Aruba requests a trial by jury on all issues so triable.

DENIAL OF PLAINTIFFS' PRAYER FOR RELIEF

68. Aruba denies that Symbol or Wireless Valley are entitled to an award of any relief at all or the relief sought in their prayer for relief against Aruba. Aruba has not infringed, directly, indirectly, contributorily or by inducement, literally or equivalently, willfully or otherwise, any of the asserted claims of the patents-in-suit. Symbol's and Wireless Valley's prayer should be denied its entirety and with prejudice, and Symbol and Wireless Valley should take nothing.

COUNTERCLAIMS

THE PARTIES

69. Aruba is a corporation organized under the laws of the State of Delaware with its principal place of business at 1322 Crossman Avenue, Sunnyvale, California 94089-1113. Aruba was founded in 2002 and went public in 2007. Aruba delivers an enterprise mobility

solution that enables secure access to data, voice and video applications across wireless and wireline enterprise networks. It has won many, many awards for its technology innovations.

70. According to the Complaint, Symbol is a corporation organized under the laws of the State of Delaware, with its principal place of business at One Motorola Plaza, Holtsville New York 11742-1300. According to filings with the U.S. Securities and Exchanges Commission, Symbol is a wholly-owned subsidiary of global behemoth Motorola, Inc., and was acquired by Motorola in September 2006.

71. According to the Complaint, Wireless Valley is a corporation organized under the laws of the State of Delaware with its principal place of business at 4515 Seton Center Parkway, Suite 300, Austin, Texas 78759. According to filings with the U.S. Securities and Exchanges Commission, Wireless Valley is a wholly-owned subsidiary of global behemoth Motorola, Inc., and was acquired by Motorola in December 2005.

JURISDICTION AND VENUE

72. This Court has subject-matter jurisdiction over Aruba's patent counterclaims, which arise under the patent laws of the United States, pursuant to 28 U.S.C. §§ 1331, 1338, 2201, and 2202.

73. This Court has personal jurisdiction over Symbol, at least because Symbol filed its Complaint for patent infringement in this Court, in response to which these counterclaims are filed.

74. This Court has personal jurisdiction over Wireless Valley, at least because Wireless Valley filed its Complaint for patent infringement in this Court, in response to which these counterclaims are filed.

75. Venue is established in this district pursuant to 28 U.S.C. § 1391 and 1400. Venue is also established in this Court because Symbol and Wireless Valley have consented to the propriety of venue in this Court by filing their respective claims for patent infringement in this Court, in response to which Aruba files these counterclaims.

COUNT 1

DECLARATORY JUDGMENT OF NON-INFRINGEMENT

('922 AND '923 PATENTS)

76. Aruba incorporates Paragraphs 1 through 66 and 69 through 75 here.

77. An actual and justiciable controversy exists between Aruba and Symbol with respect to the asserted claims of the '922 and '923 patents because Symbol has brought this action against Aruba alleging that Aruba infringes claims of the '922 and '923 patents, which allegation Aruba denies. Absent a declaration of noninfringement, Symbol will continue wrongfully to assert claims of the '922 and '923 patents against Aruba, and thereby cause Aruba irreparable injury and damage.

78. Aruba has not infringed, and does not infringe, the asserted claims of the '922 or '923 patents, either directly or indirectly, literally or under the doctrine of equivalents, willfully, or otherwise, and Aruba is entitled to a declaration to that effect.

COUNT 2

DECLARATORY JUDGMENT OF INVALIDITY

('922 AND '923 PATENTS)

79. Aruba incorporates Paragraphs 1 through 66 and 69 through 75 here.

80. An actual and justiciable controversy exists between Aruba and Symbol with respect to the asserted claims of the '922 and '923 patents because Symbol has brought this action against Aruba alleging that the asserted claims of the '922 and '923 patents are valid, which allegation Aruba denies. Absent a declaration of invalidity, Symbol will continue wrongfully to assert claims of the '922 and '923 patents against Aruba, and thereby cause Aruba irreparable injury and damage.

81. The '922 and '923 patents are invalid for failure to comply with the requirements of Title 35, United States Code, including but not limited to §§ 101, 102, 103, and/or 112, and Aruba is entitled to a declaration to that effect.

COUNT 3

DECLARATORY JUDGMENT OF UNENFORCEABILITY

('922 AND '923 PATENTS)

82. Aruba incorporates Paragraphs 1 through 66 and 69 through 75 here.

83. An actual and justiciable controversy exists between Aruba and Symbol with respect to the asserted claims of the '922 and '923 patents because Symbol has brought this action against Aruba alleging that the asserted claims of the '922 and '923 patents are enforceable, which allegation Aruba denies. Absent a declaration of unenforceability, Symbol will continue wrongfully to assert claims of the '922 and '923 patents against Aruba, and thereby cause Aruba irreparable injury and damage.

84. As set forth above, one or more people substantively involved in the prosecution of the application leading to the '922 and '923 patents were aware of information material to the patentability of the claims of the '922 and '923 patents, but withheld that information from the U.S. Patent and Trademark Office with the intent to deceive, during the prosecution of the '922 and '923 patents.

85. In light of the above, the '922 and '923 patents are not enforceable due to inequitable conduct.

COUNT 4

DECLARATORY JUDGMENT OF NON-INFRINGEMENT

('454 AND '622 PATENTS)

86. Aruba incorporates Paragraphs 1 through 66 and 69 through 75 here.

87. An actual and justiciable controversy exists between Aruba and Wireless Valley with respect to the asserted claims of the '454 and '622 patents because Wireless Valley has brought this action against Aruba alleging that Aruba infringes claims of the '454 and '622 patents, which allegation Aruba denies. Absent a declaration of noninfringement, Wireless Valley will continue wrongfully to assert claims of the '454 and '622 patents against Aruba, and thereby cause Aruba irreparable injury and damage.

88. Aruba has not infringed, and does not infringe, the asserted claims of the '454 and '622 patents, either directly or indirectly, literally or under the doctrine of equivalents, willfully, or otherwise, and Aruba is entitled to a declaration to that effect.

COUNT 5

DECLARATORY JUDGMENT OF INVALIDITY

('454 AND '622 PATENTS)

89. Aruba incorporates Paragraphs 1 through 66 and 69 through 75 here.

90. An actual and justiciable controversy exists between Aruba and Wireless Valley with respect to the asserted claims of the '454 and '622 patents because Wireless Valley has brought this action against Aruba alleging that the asserted claims of the '454 and '622 patents are valid, which allegation Aruba denies. Absent a declaration of invalidity, Wireless Valley will continue wrongfully to assert claims of the '454 and '622 patents against Aruba, and thereby cause Aruba irreparable injury and damage.

91. The '454 and '622 patents are invalid for failure to comply with the requirements of Title 35, United States Code, including but not limited to §§ 101, 102, 103, and/or 112, and Aruba is entitled to a declaration to that effect.

COUNT 6

DECLARATORY JUDGMENT OF UNENFORCEABILITY

('454 AND '622 PATENTS)

92. Aruba incorporates Paragraphs 1 through 66 and 69 through 75 here.

93. An actual and justiciable controversy exists between Aruba and Wireless Valley with respect to the asserted claims of the '454 and '622 patents because Wireless Valley has brought this action against Aruba alleging that the asserted claims of the '454 and '622 patents are enforceable, which allegation Aruba denies. Absent a declaration of unenforceability, Wireless Valley will continue wrongfully to assert claims of the '454 and '622 patents against Aruba, and thereby cause Aruba irreparable injury and damage.

94. As set forth above, one or more people substantively involved in the prosecution of the application leading to the '454 and '622 patents were aware of information material to the patentability of the claims of the '454 and '622 patents, but withheld that information from the U.S. Patent and Trademark Office with the intent to deceive, during the prosecution of the '454 and '622 patents. In addition, with respect to the '622 patent, and as set forth above, Aruba is informed and believes, and on that basis alleges, that individuals charged with a duty of candor on behalf of Wireless Valley made false and misleading statements to the U.S. Patent and Trademark Office during the prosecution of the '622 patent.

95. In light of the above, the '454 and '622 patents are not enforceable due to inequitable conduct.

DEMAND FOR A JURY TRIAL

96. Aruba requests a trial by jury on all issues so triable.

PRAYER FOR RELIEF

WHEREFORE, Aruba prays the Court as follows:

A. That the Court enter judgment for Aruba against each of Symbol and Wireless Valley on their Complaint;

B. That each of Symbol and Wireless Valley take nothing by their Complaint;

C. That the Court dismiss each of Symbol's and Wireless Valley's claims with prejudice;

D. That the Court declare each and every asserted claim of the '922, '923, '454 and '622 patents to be (a) not infringed by Aruba, (b) invalid, and (c) unenforceable;

E. That, under 35 U.S.C. § 285, the Court deem this to be an exceptional case based on the conduct of each of Symbol and Wireless Valley in commencing and pursuing this action, and that the Court award Aruba its "reasonable attorney fees" against each of Symbol and Wireless Valley;

F. That the Court award Aruba its costs of suit; and

G. That the Court award Aruba such other and additional relief as this Court deems just and proper.

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Richards, Layton & Finger
One Rodney Square
920 North King Street
P. O. Box 551
Wilmington, DE 19899
Telephone: (302) 651-7700

Attorneys for Defendant and Counter-Claimant ARUBA NETWORKS, INC.

Of Counsel:

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PAUL E. TORCHIA
ETAI LAHAV
WEIL, GOTSHAL & MANGES LLP
New York Office
767 Fifth Avenue
New York, NY 10153-0119
Telephone: (212) 310-8000

Dated: October 17, 2007

CERTIFICATE OF SERVICE

I hereby certify that on October 17, 2007, I electronically filed the foregoing with the Clerk of Court using CM/ECF which will send notification of such filing(s) to the following and which has also been served as noted:

BY HAND

Richard L. Horwitz
David E. Moore
Potter Anderson & Corroon LLP
Hercules Plaza, 6th Floor
1313 N. N. Market Street
Wilmington, DE 19801

I hereby certify that on October 17, 2007 I transmitted the document by Federal Express to the following non-registered participant:

VIA FEDERAL EXPRESS
Eric J. Lobenfeld
Ira J. Schaefer
Lawrence Brocchini
Arun Chandra
Hogan & Hartson L.L.P.
875 Third Avenue
New York, NY 10022

F. L. Cottrell III

Frederick L. Cottrell, III (#2555)
cottrell@rlf.com

EXHIBIT 3

Symbol Technologies Wins National Medal Of Technology

SYMBOL TECHNOLOGIES WINS NATIONAL MEDAL OF TECHNOLOGY

Only Company This Year To Win Nation's Highest Honor For Technological Innovation. Symbol Cited By President Clinton For Innovations In Bar Code Scanning, Mobile Computing And Wireless LAN Communications

2000-01-31 HOLTSVILLE, NY

President Clinton today announced that Symbol Technologies, Inc. will receive this year's National Medal of Technology, the nation's highest honor for technological innovation. Awarded annually since 1980 and administered by the Department of Commerce, the prestigious award goes to Symbol "for creating the global market "

Symbol is the only company to win the award this year and only the 11th corporate recipient in the 20-year history of the award. The National Medal of Technology recognizes technological innovation and advancement of the nation's global competitiveness, as well as ground-breaking contributions that commercialize a technology, create jobs, improve productivity, or stimulate the nation's growth and development in other ways.

"We honor these exceptional U.S. scientists and engineers for their achievements, contributions, and innovations that have sustained U.S. leadership across the frontiers of scientific and technological knowledge, thereby enhancing our ability to shape and improve our nation's future," said President Clinton in the White House announcement today.

of Symbol, will accept the National Medal of Technology from President Clinton at a White House ceremony on March 14, 2000.

For over 20 years, Symbol has been the world leader in the and, more recently, in and . These technologies are . Symbol's innovations include the hand-held bar code laser scanner, the scanner-integrated mobile computer, the spread spectrum wireless LAN, , PDF417 , and the . Symbol holds well over 400 issued U.S. patents.

"This award is a tribute to the hard work and perseverance of thousands of associates at Symbol over many years," said . "Symbol's breakthroughs in miniaturized bar code scanning, mobile computing and wireless data and voice network communications have enabled our customers to achieve new levels of accuracy, speed and efficiency. As we move our hand-held solutions to the next frontiers of the Internet and e-com, Symbol will continue to innovate and lead the way with our powerful tools for businesses and consumers."

Symbol Technologies, Inc. is a global leader in wireless and Internet-based mobile data management systems and services. Symbol provides its customers unique value with innovative solutions utilizing application-specific information appliances, data and voice wireless networks, and bar code and data capture scanning. Symbol and its global network of business partners provide wireless LAN and WAN

mobility solutions from the enterprise to e-commerce for industries including retail, transportation and distribution logistics, manufacturing, parcel and postal delivery, healthcare, hospitality and education. Symbol's broad range of information appliances is in use by business and consumers from the factory, to the office and in the home. Information is available from Symbol at Symbol Technologies Wins National Medal Of Technology and 1-800-722-6234.

EXHIBIT 4

Symbol Technologies Awarded National Medal Of Technology By Presid
Ceremony

SYMBOL TECHNOLOGIES AWARDED NATIONAL MEDAL OF TECHNOLOGY BY PRESIDENT CLINTON IN WHITE HOUSE CEREMONY

C

Only Company This Year To Win Nation's Highest Honor For Technology Innovation

2000-3-14 HOLTSVILLE, N.Y.
Symbol Technologies will receive this year's National Medal of Technology, the nation's highest honor for technology innovation, from President William Clinton at a ceremony today at the White House. , will accept the award.

The , was won by Symbol, "For creating the global market for laser bar code scanning and for technology innovation and practical application of mobile computing and wireless local area network technologies."

Symbol is only the 11th corporate recipient in the 20-year history of the National Medal of Technology and the only company to win the award this year. Other previous corporate winners include Bell Laboratories, Merck, 3M, Corning and DuPont.

The award recognizes technology innovation and advancement of the nation's global competitiveness, as well as ground-breaking contributions that commercialize a technology, create jobs, improve productivity, or stimulate the nation's growth and development in other ways.

"For more than 20 years, we've concentrated on practical uses of technology to create real-world systems - —that help make U.S. businesses more efficient, productive and competitive," said Dr. Swartz, who co-founded Symbol.

"The National Medal of Technology is a singular honor and validates the hard work and continuous commitment to excellence and technology innovation of many Symbol Associates."

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EXHIBIT 5

President Awards Highest U.S. Honor for Technological Innovation to Motorola

Motorola Receives National Medal of Technology

SCHAUMBURG, Ill., November 15, 2005 – On Monday, November 14, President George W. Bush announced that Motorola, Inc. (NYSE: MOT) is among the recipients of the 2004 National Medal of Technology, the nation's highest honor for technological innovation. Motorola was recognized for "over 75 years of technological achievement and leadership in the development of innovative electronic solutions, which have enabled portable and mobile communications to become the standard across society."

"It is a tremendous honor to receive the National Medal of Technology," said Motorola Chairman and CEO Ed Zander. "This award recognizes the extraordinary contributions of Motorola's employees over the company's 77 years of innovation leadership."

Motorola pioneered mobile communications with car radios and public safety radio networks in the 1930s, walkie talkies in the 1940s, and in 1969 made hearing the first words from the moon possible. In the 1980s, Motorola introduced the first commercial, handheld cellular phone. In the 1990s, Motorola premiered the first digital cellular GSM network and helped create all-digital HDTV. Today, Motorola's smart devices, networks and software make communications not just mobile, but seamless -- allowing easy, uninterrupted access to communication, information and entertainment. The company also leads in design, with award-winning products like the iconic RAZR handset.

"The National Medal of Technology is important not just because it awards innovation, but because it inspires all of us to be relentless in our pursuit of the technologies critical to maintaining our country's global economic leadership," Zander said.

Established by Congress in 1980 and first awarded in 1985, the National Medal of Technology recognizes those who have made lasting contributions to America's competitiveness, standard of living and quality of life through technological innovation and those who have substantially contributed to strengthening the nation's technological workforce. The medal is awarded annually to individuals, teams and/or companies/divisions for their outstanding contributions to the nation's economic, environmental and social well-being through the development and commercialization of technology products, processes and concepts; technological innovation; and development of the nation's technological manpower.

Applicants for the National Medal of Technology are evaluated by the National Medal of Technology Evaluation Committee. The committee makes its recommendations to the U.S. Secretary of Commerce, who in turn makes recommendations to the President for final selection. The National Medal of Technology laureates are announced by the White House and the Department of Commerce.

About Motorola
Motorola is a Fortune 100 global communications leader that provides seamless mobility products and solutions across broadband, embedded systems and wireless networks. In your home, auto, workplace and all spaces in between, seamless mobility means you can reach the people, things and information you need, on the go. Seamless mobility harnesses the power of technology convergence and enables smarter, faster, cost-effective and flexible communication. Motorola had sales of US $31.3 billion in 2004. For more information: www.motorola.com.

# # #

Media Contacts
Jennifer Weyrauch
Motorola, Inc.
847-435-5320
Jennifer.weyrauch@motorola.com

EXHIBIT 6

Chandra, Arun

Subject: FW: Symbol/Wireless Valley v. Aruba

Attachments: 1072905_2.DOC¤

From: Lobenfeld, Eric J.
Sent: Friday, February 22, 2008 4:09 PM
To: nicholas.groombridge@weil.com; Paul.Torchia@weil.com; cottrell@rlf.com
Cc: Lobenfeld, Eric J.; Horwitz, Richard L.; Moore, David E.
Subject: Symbol/Wireless Valley v. Aruba

Nick et al. - plaintiffs would like to try to get this case moving. to that end, I am attaching a proposed Scheduling Order in the hope that we could reach agreement as to its content, and propose it to Judge Farnan. Please let me have your thoughts.

Thanks.

ERIC J. LOBENFELD, PARTNER
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875 Third Avenue, New York, NY 10022
direct +1.212.918.8202 | tel +1.212.918.3000 | fax +1.212.918.3100
ejlobenfeld@hhlaw.com | http://www.hhlaw.com

EXHIBIT 7

Chandra, Arun

Subject: FW: Symbol/Wireless Valley v. Aruba

----- Original Message -----
From: Cottrell, Frederick <Cottrell@RLF.com>
To: Horwitz, Richard L.
Sent: Tue Feb 26 16:55:33 2008
Subject: RE: Symbol/Wireless Valley v. Aruba

I will speak with the client and co-counsel.

From: Horwitz, Richard L. [mailto:rhorwitz@Potteranderson.com]
Sent: Tuesday, February 26, 2008 4:11 PM
To: Cottrell, Frederick
Subject: FW: Symbol/Wireless Valley v. Aruba

What's going on with this? We have heard nothing. As I'm sure you're aware from other cases, parties often send Judge Farnan a proposed scheduling order, even if not totally agreed to, when he hasn't set a date for a status conference.

Rich

From: Lobenfeld, Eric J. [mailto:EJLobenfeld@HHLAW.com]
Sent: Friday, February 22, 2008 4:09 PM
To: nicholas.groombridge@weil.com; Paul.Torchia@weil.com; cottrell@rlf.com
Cc: Lobenfeld, Eric J.; Horwitz, Richard L.; Moore, David E.
Subject: Symbol/Wireless Valley v. Aruba

Nick et al. - plaintiffs would like to try to get this case moving. to that end, I am attaching a proposed Scheduling Order in the hope that we could reach agreement as to its content, and propose it to Judge Farnan. Please let me have your thoughts.

Thanks.

Eric J. Lobenfeld, Partner
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EXHIBIT 8

Potter Anderson & Corroon LLP
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www.potteranderson.com

Richard L. Horwitz
Partner
Attorney at Law
rhorwitz@potteranderson.com
302 984-6027 Direct Phone
302 658-1192 Fax

March 5, 2008

VIA ELECTRONIC FILING

The Honorable Joseph J. Farnan, Jr.
United States District Court
844 North King Street
Wilmington, DE 19801

Re: Symbol Technologies, Inc., et al v. Aruba Networks, Inc.
C.A. No. 07-519-JJF

Dear Judge Farnan:

We represent Plaintiffs Symbol Technologies, Inc. and Wireless Valley Communications ("Plaintiffs") in the above-referenced action. Pursuant to Fed. R. Civ. P. 16(b) and Local Rule 16.1, Plaintiffs request that the Court set a date for a scheduling conference in this case. A proposed Scheduling Order is enclosed herewith.

By way of background, Plaintiffs filed their Complaint alleging patent infringement by Defendant Aruba Networks, Inc. ("Aruba") on August 27, 2007. On October 17, 2008, Aruba filed its responsive Answer and Counterclaims; the Answer contained several affirmative defenses. Thereafter, on December 10, 2007, Plaintiffs filed their Reply to Aruba's Counterclaims. Also, on December 10, 2007, Plaintiffs moved to strike certain of Aruba's defenses; the briefing with respect to this motion was completed in January.

On February 22, 2008, Symbol's counsel sent an e-mail to Aruba's counsel enclosing a proposed Scheduling Order, and seeking comments. Aruba's counsel did not respond or acknowledge the proposal. On February 26, Symbol's counsel again inquired of Aruba's counsel concerning a schedule and asked for a response. There was none. We then learned that on February 25, 2008, Aruba filed a petition for an *inter partes* reexamination of U.S. Patent No. 7,173,922 (the "'922 patent"), one of the four patents-in-suit.

Pursuant to Local Rule 16.1(a), on March 4, 2008, Plaintiffs' counsel conferred with Defendant's counsel to seek agreement with respect to Plaintiffs' proposed Scheduling Order. Citing its petitioning for an *inter partes* reexamination of the '922 patent, Aruba's counsel declined to agree to any proposed schedule herein. Instead, Aruba's counsel indicated that it

intended to move to stay the entire case, based on its petition for reexamination of the '922 patent. Plaintiffs did not agree to the stay proposal, particularly since the petition does not involve the other three patents-in-suit. Thus, even if the Patent Office were to grant Aruba's petition, it would not impact any claim of the remaining patents-in-suit.

Accordingly, Plaintiffs believe that there is no need to further delay discovery in this action, and request that the Court set a date for a scheduling conference at the Court's earliest convenience.

Respectfully submitted,

/s/ Richard L. Horwitz

Richard L. Horwitz

RLH/msb
852947 / 32106

cc: Clerk of the Court (via hand delivery)
All Counsel of Record (via electronic mail)

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SYMBOL TECHNOLOGIES, INC., a Delaware corporation, and WIRELESS VALLEY COMMUNICATIONS, INC., a Delaware corporation,	)	
Plaintiffs/Counterclaim Defendants,	)	C.A. No. 07-519-JJF
v.	)	**JURY DEMANDED**
ARUBA NETWORKS, INC., a Delaware corporation,	)	
Defendant/Counterclaim Plaintiff.	)	

[PROPOSED] RULE 16 SCHEDULING ORDER

The parties having satisfied their obligations under Fed. R. Civ. P. 26(f),

IT IS ORDERED that:

1. **Pre-Discovery Disclosures.** The parties will exchange by **March 21, 2008** the information required by Fed. R. Civ. P. 26(a)(1) and D. Del. LR 16.1.

2. **Joinder of other Parties.** All motions to join other parties shall be filed on or before **June 15, 2008**.

3. **Settlement Conference.** Pursuant to 28 U.S.C. §636, this matter is referred to Magistrate Judge ___________________ for the purposes of exploring the possibility of a settlement. If the parties agree that they would benefit from a settlement conference, the parties shall contact the Magistrate Judge to schedule a settlement conference so as to be completed no later than the Pretrial Conference or a date ordered by the Court.

4. Discovery.

(a) Exchange and completion of contention interrogatories, identification of fact witnesses and document production shall be commenced so as to be completed by **July 15, 2008**.

(b) Maximum of **25** interrogatories, including contention interrogatories, for each side.

(c) Maximum of **100** requests for admission by each side.

(d) Maximum of **70 hours** of fact depositions by plaintiff and by defendant, excluding expert depositions. Each fact deposition limited to a maximum of seven hours per day unless extended by agreement of the parties. Depositions shall not commence until the discovery required by Paragraph 4 (a, b and c) is completed. All discovery, including that required by Paragraph 4(e) and (f) shall be completed by **January 29, 2009**.

(e) Reports from retained experts required by Fed. R. Civ. P. 26(a)(2) are due from the party having the burden of proof by **November 14, 2008**; from the party opposing by **December 15, 2008**.

(f) Any party desiring to depose an expert witness shall notice and complete said deposition no later than thirty (30) days from receipt of said expert's report, unless otherwise agreed in writing by the parties or ordered by the Court.

5. Non-Case Dispositive Motions.

(a) Any non-case dispositive motion, along with an Opening Brief, shall be filed with a Notice of Motion. The Notice of Motion shall indicate the date on which the movant seeks to have the motion heard. The date selected shall be within 30 days of the filing of the motion and allow for briefing in accordance with the Federal and Local Rules. Available motion dates will be posted on the Court's website at www.ded.uscourts.gov.

(b) At the motion hearing, each side will be allocated twenty (20) minutes to argue and respond to questions from the Court.

(c) Upon filing of the Notice of Motion, a copy of said Notice shall be sent to Chambers by e-mail at jjf_civil@ded.uscourts.gov.

6. **Amendment of the Pleadings.** All motions to amend the pleadings shall be filed on or before **July 30, 2008**.

7. **Case Dispositive Motions.** Any case dispositive motions, pursuant to the Federal Rules of Civil Procedure, shall be served and filed with an opening brief on or before **February 13, 2009**. Briefing shall be pursuant to D. Del. LR 7.1.2. No case dispositive motion may be filed more than ten (10) days from the above date without leave of the Court. The Court will issue a separate Order regarding procedures for filing summary judgment motions.

8. **Claim Construction And Markman.**

The parties shall exchange lists of those claim terms that they believe need construction and their proposed claim construction of those terms, including citations supporting that construction, on **December 30, 2008**. That list must identify any claim language that a party contends will have a meaning to a person of ordinary skill in the art that differs from the ordinary meaning. Any language not so identified will be construed according to its ordinary dictionary meaning. These lists will not be filed with the court.

Subsequent to the exchange of such lists, the parties will meet and confer to prepare a Joint Claim Construction Statement. The parties shall agree upon and file the Joint Claim Construction Statement on **January 23, 2009**. The parties will file simultaneous opening claim construction briefs on **February 13, 2009**. Simultaneous response briefs should be filed by **February 27, 2009.**

A Markman Hearing will be held on **[March 13, 2009]**. The Court, after reviewing the Joint Claim Construction Statement and briefing, will allocate time to the parties for the hearing.

9. Applications by Motion.

(a) Any applications to the Court shall be by written motion filed with the Clerk of the Court in compliance with the Federal Rules of Civil Procedure and the Local Rules of Civil Practice for the United States District Court for the District of Delaware (Amended Effective June 30, 2007). Any non-dispositive motion shall contain the statement required by D. Del. LR 7.1.1 and be made in accordance with the Court's December 15, 2006 Order on Procedures for Filing Non-dispositive motions in Patent Cases. Parties may file stipulated and unopposed Orders with the Clerk of the Court for the Court's review and signing. The Court will not consider applications and requests submitted by letter or in a form other than a motion.

(b) No facsimile transmissions will be accepted.

(c) No telephone calls shall be made to Chambers.

(d) Any party with a true emergency matter requiring the assistance of the Court shall e-mail Chambers at: jjf_civil@ded.uscourts.gov. The e-mail shall provide a short statement describing the emergency.

10. **Pretrial Conference and Trial.** After reviewing the parties' Proposed Scheduling Order, the Court will schedule a Pretrial Conference.

The Court will determine whether the trial date should be scheduled when the Scheduling Order is entered or at the Pretrial Conference. If scheduling of the trial date is

deferred until the Pretrial Conference, the parties and counsel shall anticipate and prepare for a trial to be held within sixty (60) to ninety (90) days of the Pretrial Conference.

______________________ DATE

______________________ UNITED STATES DISTRICT JUDGE

852951 / 32106

EXHIBIT 9

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FREDERICK L. COTTRELL

DIRECT DIAL NUMBER
302-651-7509
COTTRELL@RLF.COM

March 7, 2008

VIA ELECTRONIC FILING

The Honorable Joseph J. Farnan, Jr.
United States District Court
844 North King Street
Wilmington, Delaware 19801

Re: Symbol Technologies, Inc., et al. v. Aruba Networks, Inc.
C.A. No. 07-519-JJF

Dear Judge Farnan:

We represent Defendant Aruba Networks, Inc. ("Aruba"), in the above-captioned case. We write to respond to the Plaintiffs' March 5, 2008, letter to the Court requesting a scheduling conference and submitting a proposed schedule.

As Plaintiffs acknowledge in their letter, Aruba has already commenced reexamination proceedings on one of the patents in suit, the '922 patent, and intends to file a motion to stay this case shortly. Aruba intends to promptly prepare reexamination requests on the remaining patents as well.[1] Conducting a scheduling conference and setting a schedule in this case before the straightforward threshold issue of a stay of proceedings is decided would be an inefficient use of the Court's resources.

This case is in its earliest stages. None of the issues now before the Patent Office have been developed during discovery or otherwise addressed. If the Plaintiffs' patents emerge from the reexamination proceedings, the parties can proceed at that time with minimal impact on the case. This is not a case where a stay would frustrate or disrupt ongoing proceedings before the Court. In any event, Plaintiffs would not be prejudiced if they had to wait the few weeks it will take the parties to submit their briefing on the motion to stay. Both parties and the Court would benefit by first addressing the issue of whether the case will proceed at this time before expending the resources in an effort to negotiate the details of a schedule.

In their letter, Plaintiffs suggest that Aruba did not respond to their attempts to confer about a schedule. That is incorrect. I communicated with local counsel for Plaintiffs concerning

[1] Thus, Plaintiffs are incorrect in their assertion that Aruba will rely solely on the reexamination of the '922 patent.

these issues during the past two weeks. Moreover, Nicholas Groombridge, outside counsel for Aruba, contacted outside counsel for Plaintiffs by both voicemail and email on March 3, 2008. In light of the parties' fundamental differences on the issue of a stay, they could not agree on a schedule.[2]

Aruba will file its motion to stay proceedings promptly. Because this motion presents a threshold question about the course of proceedings in this case, Aruba respectfully requests that the Court consider this motion before proceeding with a scheduling conference.

Respectfully,

Frederick L. Cottrell, III

Frederick L. Cottrell, III (#2555)

FLC:srs

cc: Clerk of the Court (via hand delivery)
All Counsel of Record (via electronic mail)

---

[2] Aruba disagrees with Plaintiffs' proposed schedule even apart from the reexamination issues. Because the debate about the specific dates and discovery limits is subsidiary to the overarching question of the stay, however, Aruba does not address these details here. If the Court believes it would be useful, Aruba will be happy to confer about these issues with Plaintiffs further and submit its own dates if necessary.

EXHIBIT 10

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/780,741	02/09/2001	Robert Beach	931X	6941

29906 7590 11/28/2005

INGRASSIA FISHER & LORENZ, P.C.
7150 E. CAMELBACK, STE. 325
SCOTTSDALE, AZ 85251

EXAMINER	
SHAH, CHIRAG G	

ART UNIT	PAPER NUMBER
2664	

DATE MAILED: 11/28/2005

Please find below and/or attached an Office communication concerning this application or proceeding.

Office Action Summary	Application No.	Applicant(s)
	09/780,741	BEACH, ROBERT
	Examiner	Art Unit
	Chirag G. Shah	2664

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *28 October 2005*.

2a)☐ This action is **FINAL**. 2b)☒ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1-45* is/are pending in the application.

4a) Of the above claim(s) _____ is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1-45* is/are rejected.

7)☐ Claim(s) _____ is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☒ Notice of References Cited (PTO-892)
2) ☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)
3) ☒ Information Disclosure Statement(s) (PTO-1449 or PTO/SB/08) Paper No(s)/Mail Date _____.
4) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____.
5) ☐ Notice of Informal Patent Application (PTO-152)
6) ☐ Other: _____.

DETAILED ACTION

Response to Arguments

1. Applicant's arguments with respect to claims 1-45 have been considered but are moot in view of the new ground(s) of rejection.

Claim Rejections - 35 USC § 102

2. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (e) the invention was described in (1) an application for patent, published under section 122(b), by another filed in the United States before the invention by the applicant for patent or (2) a patent granted on an application for patent by another filed in the United States before the invention by the applicant for patent, except that an international application filed under the treaty defined in section 351(a) shall have the effects for purposes of this subsection of an application filed in the United States only if the international application designated the United States and was published under Article 21(2) of such treaty in the English language.

3. Claims 1, 15, 18, 19, 23, 27, 31, and 33 rejected under 35 U.S.C. 102(e) as being anticipated by Mahany (U.S. Patent No. 6,665,536).

Regarding claims 1, Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks **[two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65]**, the method comprising:

providing a common cell controller **[CPU Processor 41, fig. 3]** coupled to a plurality of RF ports **[two wireless radios 42, 43, fig. 3]**, wherein the common cell controller **[CPU Processor 41, fig. 3]** in conjunction with each RF port **[two wireless radios 42, 43, fig. 3]**, provides wireless medium access to all of the wireless local area subnetworks for mobile units in

a designated area associated with the RF port **[each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10]**, wherein each RF port **[radio port 42, 43 see, fig. 3]** is configured to perform low level medium access control (MAC) functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and the cell controller **[CPU Processor 41, fig. 3]** is configured to perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**, wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units **[see, col. 5, lines 5-30 and to col. 4, lines 39-65]**, and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space **[see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3] as claim**.

Regarding claim 15, Mahany discloses in fig. 3 and in col. 4, lines 39-65 of a method for transmitting signals having a wireless signal format using an RF port [two wireless radios 42, 43, fig. 3, the RF port [two wireless radios 42, 43, fig. 3] having an Ethernet interface [see fig. 11] whereby the RF port is coupled to a wired network [fig. 33, LAN 33], and having a data processor and an RF module [see fig. 3 and 11], wherein the RF port is configured to perform low level MAC functions [see col. 4, lines 39-65], and wherein the wired network comprises at least one of a physical entity and a logical entity to perform high level MAC functions [see fig. 3, 9-11 and col. 4, lines 39-65], the method comprising:

providing an Ethernet data packet formatted according to high level MAC functions over the wired network to said Ethernet interface, said Ethernet data packet encapsulating as data a data message having said wireless signal format according to high level MAC functions on said wired network [see fig. 3 and 9-11, col. 4, lines 39-65]

operating said data processor to provide said data message to said RF module [see fig. 3, col. 4, lines 39-65, CPU processor provides data message to radio for transmission];

operating said RF module to transmit said data message as an RF signal to a mobile unit [see fig. 3 and 9-11, col. 4, lines 39-65, RF radio card transmits data to mobile unit]; and

operating said RF module to transmit said data message as an RF signal over at least two wireless local area networks occupying common physical space [see fig. 3, col. 4, lines 39-65, 42 and 43 radio cards occupying common physical space].

Regarding claim 18, Mahany discloses in figs. 3 and 9-11 and in col. 4, lines 39-65 a method for receiving signals having a wireless signal format including wireless address data and

message data at an RF port, the RF port having a wired network interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions and the wired network is configured to perform high level MAC functions, the method comprising:

operating said RF module to receive RF signals from at least two wireless local area subnetworks occupying common physical space having said wireless signal format [see fig. 3 and col. 4, lines 39-65];

operating said data processor to receive wireless data signals form said RF module and provide data signals to said wired network interface comprising a data packet having a source address corresponding to said RF port formatted according to high level MAC functions on said wired network, said data packet including said wireless address data and said message data [see col. 4, lines 39-65].

Regarding claim 19, Mahany discloses in figs. 3 and 9-11 and in col. 4, lines 39-65 a method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port, the RF port having an Ethernet interface whereby the RF port is coupled to a wired network, and having a data processor and an RF module, wherein the RF port is configured to perform low level MAC functions and the wired network is configured to perform high level MAC functions, the method comprising:

receiving said RF message signals in said RF module from at least two wireless local area subnetworks occupying common physical space [see fig. 3 and col. 4, lines 39-65];;

providing said signals as data signals to said data processor; operating said data processor to interpret address data in said data signals [see fig. 3 and col. 4, lines 39-65];; and,

in dependence on said address data, encapsulating said message data and address data in an Ethernet packet and providing said Ethernet packet to said Ethernet interface for transmission on said wired network according to high level MAC functions in figs. 9-11, 3 and in col. 4, lines 39-65].

Regarding claim 23, Mahany discloses in fig. 3 and 9-11 of a simplified wireless local area network system comprising:

a computer having a data processor and a memory [see fig. 3, CPU processor, which inherently includes a memory];

a plurality of RF ports [Radio 42 and 43, fig. 3], each RF port having an RF port data processor [MAC processor, see fig. 3], an RF module and a data communications interface coupled to said computer [see fig. 3, MAC processor coupled to the CPU processor];

a first program in said memory of said computer for operating said computer data processor to perform high level MAC functions for said plurality of RF ports, said functions including association with mobile units via at least two wireless local area subnetworks occupying common physical space [see col. 4, lines 39-65]; and

a second program for operating said RF port data processor to perform low-level MAC functions [see col. 4, lines 39-65].

Regarding claim 27, Mahany discloses in fig. 3 and col. 4, lines 39-65 of a wireless access device for providing wireless access to a communication system, comprising: a modem [PCMCIA Radio card 42 and 43, see fig. 3] for sending and receiving data messages between said communications system and an RF port [see fig. 3], the RF port [PCMCIA Radio card 42 and 43, see fig. 3] comprising a data interface coupled to said modem [see fig. 3], a data processor and an RF module, said data processor being programmed to receive data messages from said modem, to format said messages for wireless data communications and to provide said formatted messages to said RF module for transmission by RF data signals to at least one mobile unit via at least two wireless local area subnetworks occupying common physical space [see col. 4, lines 39-65] , and to receive RF data signals from said at least one mobile unit via at least two wireless local area subnetworks occupying common physical space [see col. 4, lines 39-65], and to provide data messages to said modem to be sent on said communications system, wherein said RF port performs low level MAC functions and said communication system performs high level MAC functions [see col. 4, lines 39-65].

Regarding claim 31, Mahany discloses in figs. 9-11 of a method for providing wireless access to the Internet, comprising:

providing a modem coupled to the Internet and having a data communications interface connected to an RF port [see figs. 3 and 9-11, modem radio card interface RF port, accessing outside/Internet]

configuring said RF port for wireless data communication to a mobile unit having a predetermined wireless communications address [each RF port is inherently configured with an IP address to distinguish one network from another], and

providing at least one mobile unit configured with said predetermined wireless communications address for conducting RF data communications with said RF port via at least tow wireless local area subnetworks occupying common physical space, said RF port being arranged to relay communications between said mobile unit and said modem, wherein said RF port performs low level MAC functions and said Internet performs high level MAC functions [see col. 4, lines 39-65].

Regarding claim 33, Mahany discloses in fig. 1, 3, 9-11 and col. 4, lines 39-65 of a system for providing wireless data communications between mobile units and a wired network operating according to a wireless data communications protocol having high level MAC functions including association and roaming functions, comprising:

at least one RF port performing lower level MAC functions [see fig. 3 and col. 4, lines 39-65], said at least one RF port having an RF module for sending and receiving data messages to said at least one mobile unit using capable of operating via at least two wireless local area subnetworks occupying common physical space [see, fig. 3 and 9-11], having a wired interface [LAN, fig. 3] for sending and receiving data messages to and from said wired network using a wired communications protocol, and a programmed processor for relaying data messages received on said wired interface using said RF communications protocol and for relaying data

messages received by said RF module using said wired communications protocol [see fig. 3, 9-11]; and

at least one controller [CPU controller, fig. 3] for sending data messages to said wired interface of said RF port and for receiving data messages from said RF port wherein said cell controller performs said high level MAC functions [see col. 4, lines 39-65].

Claim Rejections - 35 USC § 103

4. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

5. Claims 1-6, 15, 17-20, 22-24, 26, 27, and 31-45 rejected under 35 U.S.C. 103(a) as being unpatentable over Lewis (U.S. Patent No. 6,259,898) in view of Mahany (U.S. Patent No. 6,665,536).

Referring to claim 1, Lewis discloses in **the abstract, figures 1 and 2** of a method for operating a wireless local area network having at least one RF port **(each access point 19 includes a plurality of wireless transceivers 36a and 36b as in figure 2)**, a plurality of mobile units **(21a thru 21d as in figure 1)** and a cell controller **(main processor 30 as in figure 2)** coupled to said RF port **(transceivers 36a and 36b as in figure 2)**, comprising:

operating said RF port to relay signals received from mobile units to said cell controller and to relay signals received from said cell controller to said mobile units **(As disclosed in figures 1, 2 and column 4, lines 47 to column 5, lines 25, RF transceivers 36, includes its**

own respective receiver 38 for receiving wireless RF communication from a mobile terminal 21 and a wireless transmitter 40 for transmitting wireless RF communications to a mobile terminal 21. In addition, information packets received via the transceivers 36a, 36b are communicated/rely to the main processor 30.)

operating said cell controller to control association of said mobile units with said RF port, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area subnetworks occupying common physical space **(As disclosed in figures 1, 2, and column 4, lines 47 to column 5, lines 62, Information packets which are received by the main processor 30 are reviewed by the processor 30 to determine if the information packets are directed to a mobile terminal 21 registered to the access point 19. In addition, in order to permit simultaneous operation of the transceivers 36 included in a given access point, each transceiver 36a, 36b is configured to operate on a different channel, access point 19 may include two or more peripheral ports for PCMCIA card radio. Furthermore, as in figures 1 and 2 and in column 2, lines 23 to 42 and column 5, lines 26-45 each transceiver 36a, 36b operate on different communication channels in order to avoid interference, yet the two PCMCIA radio transceivers occupy common physical space since a mobile station in the same geographic area is able to respond to a beacon sent out by the transceivers in a specific operating channel).**

operating said cell controller to send messages to and from said mobile unit via said RF port **(As disclosed in figures 1, 2 and column 4, lines 47 to column 5, lines 25, RF transceivers 36, includes its own respective receiver 38 for receiving wireless RF**

communication from a mobile terminal 21 and a wireless transmitter 40 for transmitting wireless RF communications to a mobile terminal 21. In addition, the transceivers 36a, 36b are coupled to the main processor 30 via a local bus 46 and information packets received via the transceivers 36a, 36b are communicated/rely to the main processor 30) as claim.

Referring to claims 15, **Lewis discloses in the abstract, figures 1 and 2 of** a method for transmitting signals having a wireless signals format using an RF port having an Ethernet interface (**Each Access Point 19 includes a plurality of wireless transceivers, the Network Interface Card attached via a port to the Access Point is an Ethernet network interface card or a PCMCIA radio card as in figure 2 and column 5, lines 53-62**), a data processor (**main processor 30 as in figure 2**) and an RF module (**Access Point 19 of figure 2**), comprising providing an Ethernet data packet to said Ethernet interface (**Network Interface Card such as PCMCIA as in column 5, lines 53-62**), said Ethernet data packet encapsulating as data a data message having said wireless signal format, operating said data processor to provide said data message to said RF module, and operating said RF module to transmit said data message as an RF signal over at least two wireless local area subnetworks (**as disclosed in the abstract that access point includes at two transceivers one communicating with one group of mobile terminals on one channel and another transceiver communicating to another different group of terminals on a second/separate channel**) occupying common physical space (**As disclosed in column 4, lines 47 to column 5, lines 62, the transceivers 36a, 36b are coupled to the main processor 30 via a local bus 46. Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA), intended to be forwarded onto the system backbone 17, are communicated to the main processor 30. The main**

processor forwards each packet onto the system backbone 17 to the address specified in the packet, the processor 30 receives a look-up table in the memory to determine if the mobile terminal 21 to which the packet is address is registered, if so, the processor determines from which particular transceiver 36a or 36b is assigned to communicating with particular mobile terminal 21 to which the packet is addressed. Based on such determination, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface (of the at least two wireless local area subnetwork occupying common physical space). *Lewis fails to explicitly disclose of providing a common cell controller coupled to a plurality of RF ports, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports.* Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks **[two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65]**, the method comprising:

providing a common cell controller **[CPU Processor 41, fig. 3]** coupled to a plurality of RF ports **[two wireless radios 42, 43, fig. 3]**, wherein the common cell controller **[CPU Processor 41, fig. 3]** in conjunction with each RF port **[two wireless radios 42, 43, fig. 3]**, provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port **[each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10]**, wherein each RF port **[radio port 42, 43 see, fig. 3]** is configured to perform low level medium access control (MAC) functions **[see col. 4, lines 39-65, MAC processor controls**

low level protocol functions] and the cell controller **[CPU Processor 41, fig. 3]** is configured to perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**, wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units **[see, col. 5, lines 5-30 and to col. 4, lines 39-65]**, and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space **[see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3]**. Therefore, it would have been obvious to one of ordinary skills in the art at the time of the invention to modify the teachings of Lewis to include the teachings of low-level MAC functionality by a MAC controller and high-level functionality by a cell processor as taught by Mahany. One is motivated as such in order to increase the transmission capacity available on the infrastructure.

Referring to claim 18, Lewis discloses in the **abstract, figures 1 and 2 and in column 4, lines 47 to column 5, lines 62** of a method for receiving signals having a wireless signal format including wireless address data and message data at an RF port having a wired network interface 32 a data processor **(main processor 30)** and an RF module **(Access Point)**, comprising

operating said RF module (Access Point) to receive RF signals from at least two wireless local area subnetworks (36a, 36b transceivers) occupying common physical space having said wireless signal format **(as disclosed in figures1, 2, and column 4, liens 47 to column 5, lines 62, Access Point receives simultaneous RF signals from transceivers 36a, 36b, each transceiver is configured to operate on a different communication channel occupying common physical space)** ,

operating said data processor **(main processor 30)** to receive wireless data signals from said RF module and provide data signals to said wired network interface **(as disclosed in figure 2 and column 4, lines 20-38, the main processor 30 is coupled to the system backbone 17 by way of a network interface 32. the network interface 32 permits the main processor 30 to send an d receive data packets via the wired system backbone 17)** comprising

a data packet having a source address corresponding to said RF port using a protocol for said wired network, said data packet including said wireless address data and said message data **(as disclosed in column 4, lines 47 to column 5, lines 25, information packets which are received via the transceivers 36a, 36b are communicated to the main processor 30; the main processor 30 then forwards each packet on the system backbone 17 to the address specified in the packet. Information packets, which are received by the main processor 30**

from the system backbone, are reviewed by the processor 30 to determine if the information packets are directed to a mobile terminal 21 registered to the access point 19. The processor 30 receives a look-up table in the memory to determine if the mobile terminal 21 to which the packet is address is registered, if so, the processor determines from which particular transceiver 36a or 36b is assigned to communicating with particular mobile terminal 21 to which the packet is addressed. Based on such determination, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface) as claim. *Lewis fails to explicitly disclose of providing a common cell controller coupled to a plurality of RF ports, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports.* Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks **[two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65]**, the method comprising:

providing a common cell controller **[CPU Processor 41, fig. 3]** coupled to a plurality of RF ports **[two wireless radios 42, 43, fig. 3]**, wherein the common cell controller **[CPU Processor 41, fig. 3]** in conjunction with each RF port **[two wireless radios 42, 43, fig. 3]**, provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port **[each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10]**, wherein each RF port **[radio port 42, 43 see, fig. 3]** is configured to perform low level medium access control (MAC) functions **[see col. 4, lines 39-65, MAC processor controls**

low level protocol functions] and the cell controller **[CPU Processor 41, fig. 3]** is configured to perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**, wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units **[see, col. 5, lines 5-30 and to col. 4, lines 39-65]**, and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space **[see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3]**. Therefore, it would have been obvious to one of ordinary skills in the art at the time of the invention to modify the teachings of Lewis to include the teachings of low-level MAC functionality by a MAC controller and high-level functionality by a cell processor as taught by Mahany. One is motivated as such in order to increase the transmission capacity available on the infrastructure.

Referring to claim 19, **Lewis discloses in the abstract, figures 1 and 2 of** a method for receiving RF message signals having a wireless signal format including an address data format and message data using an RF port having an Ethernet interface **(Each Access Point 19 includes a plurality of wireless transceivers, the Network Interface Card attached via a port to the Access Point is an Ethernet network interface card or a PCMCIA radio card as in figure 2 and column 5, lines 53-62)**, a data processor **(main processor 30)** and an RF module **(access point 19)**, comprising

receiving said RF message signals in said RF module **(Access Point 19)** from at least two wireless local area subnetworks (36a and 36b transceivers) occupying common physical space and providing said signals as data signals to said data processor (main processor 30) **(As disclosed in column 4, lines 47 to column 5, lines 62, the transceivers 36a, 36b are coupled to the main processor 30 via a local bus 46. Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA), intended to be forwarded onto the system backbone 17, are communicated to the main processor 30. In addition, as disclosed in the abstract that access point includes at two transceivers one communicating with one group of mobile terminals on one channel and another transceiver communicating to another different group of terminals on a second/separate channel)** as disclosed in ,

operating said data processor to interpret address data in said data signals and, in dependence on said address data encapsulating said message data and address data in an Ethernet packet and providing said Ethernet packet to said Ethernet interface **(As disclosed in column 4, lines 47 to column 5, lines 62, Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA), intended to be forwarded onto**

the system backbone 17, are communicated to the main processor 30. The main processor forwards each packet onto the system backbone 17 to the address specified in the packet, the processor 30 receives a look-up table in the memory to determine if the mobile terminal 21 to which the packet is address is registered, if so, the processor determines from which particular transceiver 36a or 36b is assigned to communicating with particular mobile terminal 21 to which the packet is addressed. Based on such determination, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface (of the at least two wireless local area subnetwork occupying common physical space). *Lewis fails to explicitly disclose of providing a common cell controller coupled to a plurality of RF ports, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports.* Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks **[two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65]**, the method comprising:

providing a common cell controller **[CPU Processor 41, fig. 3]** coupled to a plurality of RF ports **[two wireless radios 42, 43, fig. 3]**, wherein the common cell controller **[CPU Processor 41, fig. 3]** in conjunction with each RF port **[two wireless radios 42, 43, fig. 3]**, provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port **[each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10]**, wherein each RF port **[radio port 42, 43 see, fig. 3]** is configured to perform low

level medium access control (MAC) functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and the cell controller **[CPU Processor 41, fig. 3]** is configured to perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**, wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units **[see, col. 5, lines 5-30 and to col. 4, lines 39-65]**, and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space **[see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3]**. Therefore, it would have been obvious to one of ordinary skills in the art at the time of the invention to modify the teachings of Lewis to include the teachings of low-level MAC functionality by a MAC controller and high-level functionality by a cell processor as taught by Mahany. One is motivated as such in order to increase the transmission capacity available on the infrastructure.

Referring to claim 23, Lewis discloses in the **abstract, figure 1 and figure 2** of a simplified wireless local area network system **(LAN 15)** comprising:

a computer having a data processor **(main processor 30)** and a memory **(34)**;

an RF port **(interface)** having an RF port data processor **(Network Interface Card/PCMCIA radio card)**, an RF module **(Access Point 19)** and a data communications interface coupled to said computer;

a first program in said memory 34 of said computer for operating said computer data processor to perform first wireless data communications functions said functions including association with mobile units via at least two wireless local area subnetworks occupying common physical space (**As disclosed in column 4, lines 47 to column 5, lines 62, Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA), intended to be forwarded onto the system backbone 17, are communicated to the main processor 30. The main processor forwards each packet onto the system backbone 17 to the address specified in the packet, the processor 30 receives a look-up table in the memory to determine if the mobile terminal 21 to which the packet is address is registered, if so, the processor determines from which particular transceiver 36a or 36b is assigned to communicating with particular mobile terminal 21 to which the packet is addressed. Based on such determination, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface (of the at least two wireless local area subnetwork occupying common physical space**). **In addition, as disclosed in the abstract that access point includes at two transceivers one communicating with one group**

of mobile terminals on one channel and another transceiver communicating to another different group of terminals on a second/separate channel),

and a second program for operating said RF port (Network Ethernet Interface) data processor to perform second wireless data communications functions (**Based on the determination of the first program as disclosed in column 4, lines 47 to column 5, lines 62, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface (of the at least two wireless local area subnetwork occupying common physical space)**. *Lewis fails to explicitly disclose of providing a common cell controller coupled to a plurality of RF ports, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports.* Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks [**two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65**], the method comprising:

providing a common cell controller [**CPU Processor 41, fig. 3**] coupled to a plurality of RF ports [**two wireless radios 42, 43, fig. 3**], wherein the common cell controller [**CPU Processor 41, fig. 3**] in conjunction with each RF port [**two wireless radios 42, 43, fig. 3**], provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port [**each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10**], wherein each RF port [**radio port 42, 43 see, fig. 3**] is configured to perform low level medium access control (MAC) functions [**see col. 4, lines 39-65, MAC processor controls**

low level protocol functions] and the cell controller **[CPU Processor 41, fig. 3]** is configured to perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**, wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units [**see, col. 5, lines 5-30 and to col. 4, lines 39-65**], and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space [**see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3**]. Therefore, it would have been obvious to one of ordinary skills in the art at the time of the invention to modify the teachings of Lewis to include the teachings of low-level MAC functionality by a MAC controller and high-level functionality by a cell processor as taught by Mahany. One is motivated as such in order to increase the transmission capacity available on the infrastructure.

Referring to claim 27, Lewis discloses in **figures 1, 2 and in column 4, lines 47 to column 5, lines 25** of a wireless access device **(transceivers 36a, 36b)** for providing wireless access to a communication system **(figure 2)**, comprising a modem **(network interface cards intended for a wireless local area network inherently comprise a radio modem, whereby it is possible to set up a wireless data transmission connection to the radio modem of the local area network as specified in figure 2)** for sending and receiving data messages on said communications system and an RF port **(access point 19 may include two or more peripheral ports (e.g., PCMCIA card slots) for receiving respective transceiver radios)** , comprising a data interface coupled to said modem **(figure 1 and 2)** , a data processor **(main processor 20)** and an RF module **(Access Point 19)**, said processor **(main processor 20)** being programmed to receive data messages from said modem , to format said messages for wireless data communications and to provide said formatted messages to said RF module **(Access Point 19)** for transmission by RF data signals to at least one remote station via at least two wireless local area subnetworks occupying common physical space **(as disclosed in the abstract that access point includes at two transceivers one communicating with one group of mobile terminals on one channel and another transceiver communicating to another different group of terminals on a second/separate channel)**, and to receive RF data signals from said at least one remote station **(mobile stations of figure 1)** via at least two wireless local area subnetworks occupying common physical space, and to provide data messages to said modem to be sent on said communications system **(As disclosed in column 4, lines 47 to column 5, lines 62, Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA), intended to be forwarded onto the system backbone 17, are**

communicated to the main processor 30. The main processor forwards each packet onto the system backbone 17 to the address specified in the packet, the processor 30 receives a look-up table in the memory to determine if the mobile terminal 21 to which the packet is address is registered, if so, the processor determines from which particular transceiver 36a or 36b is assigned to communicating with particular mobile terminal 21 to which the packet is addressed. Based on such determination, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface (of the at least two wireless local area subnetwork occupying common physical space) as claim. *Lewis fails to explicitly disclose of providing a common cell controller coupled to a plurality of RF ports, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports.* Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks **[two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65]**, the method comprising:

providing a common cell controller **[CPU Processor 41, fig. 3]** coupled to a plurality of RF ports **[two wireless radios 42, 43, fig. 3]**, wherein the common cell controller **[CPU Processor 41, fig. 3]** in conjunction with each RF port **[two wireless radios 42, 43, fig. 3]**, provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port **[each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10]**, wherein each RF port **[radio port 42, 43 see, fig. 3]** is configured to perform low level medium access control (MAC) functions **[see col. 4, lines 39-65, MAC processor controls**

low level protocol functions] and the cell controller **[CPU Processor 41, fig. 3]** is configured to perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**, wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units **[see, col. 5, lines 5-30 and to col. 4, lines 39-65]**, and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space **[see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3]**. Therefore, it would have been obvious to one of ordinary skills in the art at the time of the invention to modify the teachings of Lewis to include the teachings of low-level MAC functionality by a MAC controller and high-level functionality by a cell processor as taught by Mahany. One is motivated as such in order to increase the transmission capacity available on the infrastructure.

Referring to claim 31, Lewis discloses in figure 1 of a method for providing wireless access to the Internet over the PSTN, comprising providing a modem coupled to the Internet **(network interface cards intended for a wireless local area network inherently comprise a radio modem, whereby it is possible to set up a wireless data transmission connection to the radio modem of the local area network as specified in figure 2)** and having a data communications interface **(main processor 30 of figure 2)** connected to an RF port **(PCMCIA slot of the transceiver/PCMCIA card as disclosed in figure 2 and column 5, lines 46-62)**, configuring said RF port for wireless data communication to a mobile unit having a predetermined wireless communications address **(as disclosed in the abstract, column 2, lines 22 to 64, the RF port having the PCMCIA/transceivers 36a, 36b is configured to be operating via first frequency hopping sequence to a plurality of mobile devices and second frequency hopping sequence to a plurality of different mobile devices respectively)**, and

providing at least one mobile unit (particular mobile terminal 21) configured with said predetermined wireless communications address for conducting RF data communications with said RF port (36a or 36b) via at least two wireless local area subnetworks occupying common physical space, said RF port being arranged to relay communications between said mobile unit and said modem **(As disclosed in column 4, lines 47 to column 5, lines 62, the transceivers 36a, 36b are coupled to the main processor 30 via a local bus 46. Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA), intended to be forwarded onto the system backbone 17, are communicated to the main processor 30. The main processor forwards each packet onto the system backbone 17 to the address specified in the packet, the processor 30 receives a look-up table in the memory**

to determine if the mobile terminal 21 to which the packet is address is registered, if so, the processor determines from which particular transceiver 36a or 36b is assigned to communicating with particular mobile terminal 21 to which the packet is addressed. Based on such determination, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface (of the at least two wireless local area subnetwork occupying common physical space) as claim. *Lewis fails to explicitly disclose of providing a common cell controller coupled to a plurality of RF ports, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports.* Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks **[two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65]**, the method comprising:

providing a common cell controller **[CPU Processor 41, fig. 3]** coupled to a plurality of RF ports **[two wireless radios 42, 43, fig. 3]**, wherein the common cell controller **[CPU Processor 41, fig. 3]** in conjunction with each RF port **[two wireless radios 42, 43, fig. 3]**, provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port **[each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10]**, wherein each RF port **[radio port 42, 43 see, fig. 3]** is configured to perform low level medium access control (MAC) functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and the cell controller **[CPU Processor 41, fig. 3]** is configured to

perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**, wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units **[see, col. 5, lines 5-30 and to col. 4, lines 39-65]**, and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space **[see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3]**. Therefore, it would have been obvious to one of ordinary skills in the art at the time of the invention to modify the teachings of Lewis to include the teachings of low-level MAC functionality by a MAC controller and high-level functionality by a cell processor as taught by Mahany. One is motivated as such in order to increase the transmission capacity available on the infrastructure.

Referring to claim 33, Lewis discloses in **figure 1, 2 and column 4, lines 47 to column 5, lines 62** the system for sending and receiving data messages to at least one mobile unit **(mobile terminal 21n)**, comprising

at least one RF port **(PCMCIA slot as in figures 1, 2, and in column 5, lines 54-62)** having an RF module **(Access Point)** for sending and receiving data messages to said at least one mobile unit **(mobile terminal 21)** using a first RF communications protocol (**Ethernet protocol as disclosed in column 4, lines 47 to column 5, lines 62, Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA)** capable of operating via at least two wireless local area subnetworks occupying common physical space, having a wired interface **(figure 2, The main processor 30 is coupled to the system backbone 17 by a network interface 32)** for sending and receiving data messages using a wired communications protocol, and

a programmed processor **(main processor 30 of figure 2)** for relaying data messages **(packets)** received on said wired interface **(32)** using said RF communications protocol **(WLAN)** and for relaying data messages received by said RF module **(Access Point)** using said wired communications protocol **(as disclosed in column 4, lines 19 to column 5, lines 62)**, and

at least one cell controller **(main processor 30 of figure 2)** for sending data messages to said wired interface 32 of said RF port and for receiving data messages from said RF port using said wired communications protocol (**as disclosed figure 2 and in column 4, lines 19 to column 5, lines 25, the main processor 30 is coupled to the system backbone 17 by a network interface 32. The network interface 32 permits the main processor 30 to send and receive data packets via the system backbone 17 using conventional techniques. The information**

packets are received by the main processor 30 from the system backbone 17). *Lewis fails to explicitly disclose of providing a common cell controller coupled to a plurality of RF ports, wherein each RF port is configured to perform low level medium access control (MAC) functions and the cell controller is configured to perform high level MAC functions for the coupled plurality of RF ports.* Mahany discloses in **figs. 1, 3 and in col. 4, lines 39-65** of a method for operating: a multiple overlapping wireless local area subnetworks **[two wireless adapter able to communicate with multiple networks, see col. 4, lines 39-65]**, the method comprising:

providing a common cell controller **[CPU Processor 41, fig. 3]** coupled to a plurality of RF ports **[two wireless radios 42, 43, fig. 3]**, wherein the common cell controller **[CPU Processor 41, fig. 3]** in conjunction with each RF port **[two wireless radios 42, 43, fig. 3]**, provides wireless medium access to all of the wireless local area subnetworks for mobile units in a designated area associated with the RF port **[each wireless radio supports and provides a medium access to all of the wireless local area subnetworks for mobile units, see figs. 3, 7a, 9 and 10]**, wherein each RF port **[radio port 42, 43 see, fig. 3]** is configured to perform low level medium access control (MAC) functions [**see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and the cell controller **[CPU Processor 41, fig. 3]** is configured to perform high level MAC functions for the coupled plurality of RF ports **[see col. 4, lines 39-65, CPU processor controls the high-level communications protocol functions]**;

using the cell controller **[CPU Processor 41, fig. 3]** to provide multiple service set identifications through each RF port **[each radio includes an identification, see fig. 3]**, wherein each service set identification is associated with a corresponding wireless subnetwork **[each wireless radio is associated with a corresponding wireless subnetwork, see figs. 9 and 10]**,

wherein said RF ports are operated to perform low level MAC functions **[see col. 4, lines 39-65, MAC processor controls low level protocol functions]** and to relay signals received from mobile units to said cell controller and to relay signals received from the cell controller to said mobile units **[see, col. 5, lines 5-30 and to col. 4, lines 39-65]**, and

wherein said cell controller **[CPU Processor 41, fig. 3]** is operated to control association of said mobile units **[mobile units of fig. 9 and 10]** with said RF port **[radio port 42, 43 see, fig. 3]**, including sending and receiving association signals between said RF port and said cell controller, said association of said mobile units utilizing at least two wireless local area networks occupying common physical space **[see, col. 5, lines 5-30 and to col. 4, lines 39-65 and fig. 3]**. Therefore, it would have been obvious to one of ordinary skills in the art at the time of the invention to modify the teachings of Lewis to include the teachings of low-level MAC functionality by a MAC controller and high-level functionality by a cell processor as taught by Mahany. One is motivated as such in order to increase the transmission capacity available on the infrastructure.

Referring to claim 2, Lewis discloses in column 4, lines 47 to column 5, lines 62 and column 9, lines 50-55 of a method for operating a wireless local area network as specified in Claim 1, wherein signals are sent between said RF port (PCMCIA Slot) and said cell controller (main processor 30) using a first data protocol (NIC/PCMCIA radio card), and wherein signals are sent between said RF ports (transceivers 36a, 36b) and said mobile units (21) using a second data protocol (802.11, frequency hopping) , and wherein said signals between said RF port (transceivers 36a, 36b) and said cell controllers (main processor 30) comprise data packets using

said first data protocol (NIC/PCMCIA radio) encapsulating data packets using said second data protocol (802.11 as disclosed in column 9, lines 50-55) as claim.

Referring to claims 3 and 20, Lewis discloses a method for operating a wireless local area network as specified in Claim 2 wherein said first protocol is an Ethernet protocol (As disclosed in column 4, lines 47 to column 5, lines 62, Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA) clearly establishing that the first protocol is an Ethernet protocol as claim.

Referring to claim 4, Lewis discloses in column 9, that a convention frequency hopping system utilizes a method for operating a wireless local area network as specified in Claim 3 wherein said second protocol is an IEEE Standard 802.11 protocol as claim.

Referring to claim 5, Lewis discloses in the abstract, column 2, lines 23-42 a method for operating a wireless local area network as specified in Claim 4 wherein said at least two wireless local area subnetworks (transceivers 36a, 36b) comprise a subnetwork for public use (first frequency hopping sequence) and a subnetwork for secure (second frequency hopping sequence) based on a predetermined criteria use as claim.

Referring to claim 6, Lewis discloses in the abstract and in column 2, lines 23-42 that a method for operating a wireless local area network as specified in Claim 5, wherein upon activation of said subnetwork for secure use (specific frequency hopping sequence channel), suspending service on said subnetwork for public use (based on a predetermined criteria, specific frequency hopping sequence channel may not provide access to other pubic channels) as claim.

Referring to claim 17 and 22, Lewis discloses in column 4, lines 47 to column 5, lines 25 a method as specified in Claim 15 further comprising operating said data processor (main processor 30) to control said radio module (transceivers/access point) as claim.

Referring to claim 24, Lewis discloses in column 4, lines 47 to column 5, lines 60 a system as specified in Claim 23 wherein said second program operates said RF port data processor 30 to perform second wireless data communications functions, including control of said RF module (Access Point) as claim.

Referring to claim 26, Lewis discloses in column 4, lines 47 to column 5, line 60 of a system as specified in Claim 23 wherein said second program is stored in said computer memory 34 and wherein said RF port data processor 30 is arranged to download said second program (as disclosed memory provides the processor a look-up table to determine if the mobile terminal is registered as disclosed in column 4, lines 47 to column 5, lines 25) as claim.

Referring to claim 32, Lewis discloses in column 6, lines 13-59 wherein said step of providing said mobile unit 21, comprises providing a computer having an RF port (Network Interface Card/PCMCIA which receives beacons from the transceivers of the access points as disclosed in column 6, lines 13-59) as claim.

Referring to claim 34, Lewis discloses in figure 1, 2 and column 4, lines 46 to column 5, lines 62 wherein there are provided a plurality of said RF ports (PCMCIA Slots with transceivers as disclosed in column 5, lines 53-62), and wherein said cell controller (main processor 30) is arranged to address said data messages to said RF ports using said wired communication protocol.

Referring to claim 35, Lewis discloses in column 4, lines 46-62 and in figures 1 and 2 of a system as specified in claim 34 wherein said at least one mobile unit (21a-21d of figure 1) is associated with one of said RF ports (transceiver 36a or 36b having a PCMCIA radio card). and wherein said processor (main processor 30) is programmed to interpret source address data received in said RF communications protocol and for relaying a received message using said wired communications protocol only if said source address data corresponding to a mobile unit associated with said RF port (As disclosed in column 4, lines 47 to column 5, lines 62, Information (Ethernet) packets are received via the transceivers 36a, 36b (Ethernet Interface/NIC/PCMCIA), intended to be forwarded onto the system backbone 17, are communicated to the main processor 30. The main processor forwards each packet onto the system backbone 17 to the address specified in the packet, the processor 30 receives a look-up table in the memory to determine if the mobile terminal 21 to which the packet is address is registered, if so, the processor determines from which particular transceiver 36a or 36b is assigned to communicating with particular mobile terminal 21 to which the packet is addressed. Based on such determination, the processor 30 forwards the received packet to the processor of the appropriate Ethernet interface (of the at least two wireless local area subnetwork occupying common physical space) as claim.

Referring to claim 36, Lewis discloses wherein said cell controller (main processor 30) is arranged to provide messages to said RF port (NIC slot of mobile terminal 21a-21d of figure 1) comprising mobile unit (mobile unit 21) address data and message data encapsulated in a data packet following said wired communications protocol (as disclosed in column 4, lines 46 to column 5, lines 62) as claim.

Referring to claim 37, Lewis discloses wherein a cell controller (main processor 30) is arranged to provide said mobile unit (21 of figure 1) address data and said message data in said RF communications protocol encapsulated in said wired communications format (as disclosed in column 4, lines 46 to column 5, lines 62) as claim.

Referring to claim 38, Lewis discloses wherein said RF port (transceiver slot 36a, 36b) is arranged to encapsulate messages received by said RF module (Access Point) in a data packet using said wired communication protocol as disclosed in (column 4, lines 46 to column 5, lines 62) as claim

Referring to claim 39, Mahany discloses in col. 5, lines 33-44 wherein the cell controller provides extended service set identifiers/addresses.

Referring to claim 40, Mahany discloses the cell controller provides basic service identifiers/addresses.

Referring to claim 41, Mahany discloses in col. 6,lines 1-7 where the RF port allocates data bandwidth amongst the service set identifications based on commands from cell controller.

Referring to claim 42, Mahany discloses in col. 1, lines 35-42 of WLAN's use frequency transmission to communicate between roaming computer devices, inherently establishing wherein the RF port generates 802.11 beacon for each service set identifier.

Referring to claim 43, Mahany discloses in col. 4,lines 56-65 wherein the cell controller determines which one of the multiple overlapping wireless local areas subnetworks a mobile unit communicating through an RF port is operating on.

Referring to claim 44, Mahany discloses in col. 5, lines 5-16 that high level protocol, which includes security protocols are handled by the cell controller verifies levels of security

provided in connection with access by mobile units to the multiple overlapping wireless local area networks.

Referring to claim 45, Mahany discloses in col. 5, lines 45-54 that CPU processor, the cell controller prioritizes communication based on quality information through the multiple overlapping wireless local area subnetworks.

Claim Rejections - 35 USC § 103

6. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

7. Claims 7-14 rejected under 35 U.S.C. 103(a) as being unpatentable over Lewis in view of Mahany as applied above, and further in view of Bahl (U.S. Patent No. 6,629,151).

Referring to claim 7, Lewis discloses in figures 1, 2, 4 and column 4, lines 46 to column 5, lines 62 a method for operating an RF port (transceiver/PCMCIA port 36a, 36b) having a radio module (PCMCIA radio card as in column 5, lines 53-62), a digital processor (main processor 30 figure 2), memory (memory 34 of figure 2), comprising storing a bootloader program in said and operating said RF port under said downloaded instructions to send and receive messages over at least two wireless local area subnetworks occupying common physical space using said radio module (as discloses in figure 4 and in column 7, lines 17-57, the processor 30 refers to its look-up table in the memory 34 to see if the mobile terminal 21 identified in the packet is included, if

yes, the processor selects the corresponding transceiver 36 assigned to the mobile terminal 21 indicated in the look-up table). Lewis discloses of accessing the look-up table within the memory in order for the processor to download instruction. Lewis however fails to explicitly disclose of random access memory and read-only memory and read-only memory, operating said digital processor to download instructions from a computer to said random access memory using said bootloader program. Bahl discloses in figure 1 of a system memory, which includes ROM 24 and RAM25 and further discloses in the respective portions of the specification that the ROM 24 helps to transfer information between elements within the personal computer having a processor 21. The processor 21 downloads instruction from RAM25 using program modules. Therefore, it would have been obvious to one of ordinary skill in the art to modify the explicit teaching of ROM and RAM within the system memory of a computer as taught by Bahl into Lewis in view of Mahany's invention in order to provide multi-type of computer readable media which can store data that is accessible by a computer in establishing wireless LAN communication.

Referring to claims 8 and 9, Lewis discloses in column 4, lines 47 to column 5, lines 62 wherein said step of operating said RF port (PCMCIA radio card within the RF slot) comprises receiving messages from said computer including protocol message portions for RF message transmission, and transmitting said message including said protocol message portions as an RF and sending RF messages to the computer as data signals encapsulated in a further message protocol (transceivers 36a, 36b receive information packets from a mobile station for RF message transmission and transmit the information packets as a RF signal to the processor, the

processor 30 determines if the mobile terminal 21 to which the packet is addressed is registered if so, based on the determination, processor forwards RF message to the mobile station) as claim.

Referring to claim10, Lewis discloses in column 4, lines 47 to column 5, lines 62 a method as specified in Claim 9 further comprising interpreting said RF protocol using said downloaded instructions and sending said RF messages to said computer only if said RF messages include an identification of said RF port (the processor 30 reviews a look-up table in the memory to determine if the mobile terminal 21 to which the packet is addressed is registered, if so, processor determines which particular transceiver is assigned to communicating with particular terminal 21 to which the packet is address, based on the determination the RF message is forwarded to the mobile station if the message includes an identification of the RF transceiver port) as claim .

Referring to claim 11, 13, and 14 Lewis discloses in column 4, lines 47 to column 5, lines 62 a method as specified in Claim 7 wherein said downloaded instructions configure (each transceiver is configured to operate on a different communication channel) said computer and said RF port to operate as an access point or mobile unit for communication with mobile units as claim

Referring to claim 12, Lewis discloses in column 6, lines 13-59 wherein said computer (processor 30) is operated to control association of said mobile units with said computer and RF port (when the mobile terminal 21 registers with the transceiver 36a, the main processor 30 disables the secondary transceiver 36b by causing it not to respond to the request to register broadcast by mobile terminal 21) as claim.

8. Claims 16, 21 and 25 rejected under 35 U.S.C. 103(a) as being unpatentable over Lewis in view of Mahany as applied above, further in view of Jusa et al. (U.S. Patent No. 6,031,863).

Referring to claim 16, 21 and 25, Lewis discloses in figure 2 of a main processor 30. Lewis fails to disclose operating said data processor to perform a cyclic redundancy computation on said data message and adding the result thereof to said data message. Jusa et al teaches of a Wireless LAN System. Jusa et al discloses in figure 8 and column 7, lines 40-65 that the processor within the base station device performs frame check sequence to detect an error in the entirety of the frame using a CRC code indicative of an error detection code. Therefore, it would have been obvious to one of ordinary skill in the art to modify the teachings of Lewis in view of Mahany to include teachings of CRC as taught by Jusa et al in order to detect an error in the entirety of the frame providing accuracy and quality of service.

9. Claims 28-30 rejected under 35 U.S.C. 103(a) as being unpatentable over Lewis in view of Mahany as applied above, and further in view of Gilbert et al. (U.S. Patent No. 6,205,495).

Referring to claim 28 and 29, Lewis discloses in figure 2 of network interface cards (PCMCIA Card) intended for a wireless local area network inherently comprise a radio modem, whereby it is possible to set up a wireless data transmission connection to the radio modem of the local area network. Lewis in view of Mahany fails to discloses that wireless access device as specified in Claim 27 wherein said communications system is a DSL communications system connected to the Internet, and wherein said modem comprises a DSL modem and a wireless access device as specified in Claim 27 wherein said communications system is a two-way cable communications system connected to the Internet, and wherein said modem comprises a cable

modem. Gilbert discloses in figure 2 and 3 and column 4, lines 1-25 and column 6, lines 12-27 that network communications device 330 which comprises a modem for communicating over network 336 includes a PCMCIA interface 332 and a modem interface 334 for converting information received from base station 320 into a format compatible with network 336, modem 330 may be a cable modem or DSL modem. Therefore, it would have been obvious to one of ordinary skill in the art to modify the PCMCIA card having a radio modem to be a cable modem or DSL modem in order to be in a format compatible with given respective cable or DSL network.

Referring to claim 30, Lewis discloses in column 4, liens 47-60 that each access point 19 includes a plurality of wireless transceivers, such transceivers 36 may be RF, optical, infrared, thus clearly establishing wherein said communication system may comprise a fiber optic system, and wherein said modem comprises a fiber optical modem as claim.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Chirag G. Shah whose telephone number is 571-272-3144. The examiner can normally be reached on M-F 8:30-5:00.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Wellington Chin can be reached on 571-272-3134. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free).

cgs
November 16, 2005

Chirag Shah

Chirag Shah, Patent Examiner 2664

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	Examiner Chirag G. Shah	Art Unit 2664	Page 1 of 1

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	B	US-5,960,344	09-1999	Mahany, Ronald L.	455/432.2
	C	US-6,031,863	02-2000	Jusa et al.	375/132
	D	US-6,205,495	03-2001	Gilbert et al	710/8
	E	US-6,259,898	07-2001	Lewis, Daniel E.	455/103
	F	US-6,629,151	09-2003	Bahl, Paramvir	709/250
	G	US-6,681,259	01-2004	Lemilainen et al.	709/250
	H	US-			
	I	US-			
	J	US-			
	K	US-			
	L	US-			
	M	US-			

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
09/780,741	02/09/2001	Robert Beach	931X	6941

29906 7590 04/26/2006

INGRASSIA FISHER & LORENZ, P.C.
7150 E. CAMELBACK, STE. 325
SCOTTSDALE, AZ 85251

EXAMINER	
SHAH, CHIRAG G	
ART UNIT	PAPER NUMBER
2616	

DATE MAILED: 04/26/2006

Please find below and/or attached an Office communication concerning this application or proceeding.

Interview Summary	Application No. 09/780,741	Applicant(s) BEACH, ROBERT
	Examiner Chirag G. Shah	Art Unit 2616

All participants (applicant, applicant's representative, PTO personnel):

(1) *Chirag G. Shah*. (3)_____.

(2) *Tim Lorenz*. (4)_____.

Date of Interview: *20 April 2006*.

Type: a)☒ Telephonic b)☐ Video Conference
c)☐ Personal [copy given to: 1)☐ applicant 2)☐ applicant's representative]

Exhibit shown or demonstration conducted: d)☐ Yes e)☐ No.
If Yes, brief description: _____.

Claim(s) discussed: *1*.

Identification of prior art discussed: *Maheny U.S. Patent No. 6,665,536*.

Agreement with respect to the claims f)☐ was reached. g)☒ was not reached. h)☐ N/A.

Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments: *Examiner's proposed amendments will be considered and futher search will be conducted. No agreement was reached*.

(A fuller description, if necessary, and a copy of the amendments which the examiner agreed would render the claims allowable, if available, must be attached. Also, where no copy of the amendments that would render the claims allowable is available, a summary thereof must be attached.)

THE FORMAL WRITTEN REPLY TO THE LAST OFFICE ACTION MUST INCLUDE THE SUBSTANCE OF THE INTERVIEW. (See MPEP Section 713.04) If a reply to the last Office action has already been filed, APPLICANT IS GIVEN A NON-EXTENDABLE PERIOD OF THE LONGER OF ONE MONTH OR THIRTY DAYS FROM THIS INTERVIEW DATE, OR THE MAILING DATE OF THIS INTERVIEW SUMMARY FORM, WHICHEVER IS LATER, TO FILE A STATEMENT OF THE SUBSTANCE OF THE INTERVIEW. See Summary of Record of Interview requirements on reverse side or on attached sheet.

Examiner Note: You must sign this form unless it is an Attachment to a signed Office action.

4/20/06
Examiner's signature, if required

Summary of Record of Interview Requirements

Manual of Patent Examining Procedure (MPEP), Section 713.04, Substance of Interview Must be Made of Record
A complete written statement as to the substance of any face-to-face, video conference, or telephone interview with regard to an application must be made of record in the application whether or not an agreement with the examiner was reached at the interview

Title 37 Code of Federal Regulations (CFR) § 1.133 Interviews
Paragraph (b)
In every instance where reconsideration is requested in view of an interview with an examiner, a complete written statement of the reasons presented at the interview as warranting favorable action must be filed by the applicant An interview does not remove the necessity for reply to Office action as specified in §§ 1 111, 1 135 (35 U S C. 132)

37 CFR §1 2 Business to be transacted in writing.
All business with the Patent or Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt

The action of the Patent and Trademark Office cannot be based exclusively on the written record in the Office if that record is itself incomplete through the failure to record the substance of interviews.

It is the responsibility of the applicant or the attorney or agent to make the substance of an interview of record in the application file, unless the examiner indicates he or she will do so. It is the examiner's responsibility to see that such a record is made and to correct material inaccuracies which bear directly on the question of patentability.

Examiners must complete an Interview Summary Form for each interview held where a matter of substance has been discussed during the interview by checking the appropriate boxes and filling in the blanks Discussions regarding only procedural matters, directed solely to restriction requirements for which interview recordation is otherwise provided for in Section 812.01 of the Manual of Patent Examining Procedure, or pointing out typographical errors or unreadable script in Office actions or the like, are excluded from the interview recordation procedures below. Where the substance of an interview is completely recorded in an Examiners Amendment, no separate Interview Summary Record is required

The Interview Summary Form shall be given an appropriate Paper No., placed in the right hand portion of the file, and listed on the "Contents" section of the file wrapper In a personal interview, a duplicate of the Form is given to the applicant (or attorney or agent) at the conclusion of the interview. In the case of a telephone or video-conference interview, the copy is mailed to the applicant's correspondence address either with or prior to the next official communication. If additional correspondence from the examiner is not likely before an allowance or if other circumstances dictate, the Form should be mailed promptly after the interview rather than with the next official communication.

The Form provides for recordation of the following information:
- Application Number (Series Code and Serial Number)
- Name of applicant
- Name of examiner
- Date of interview
- Type of interview (telephonic, video-conference, or personal)
- Name of participant(s) (applicant, attorney or agent, examiner, other PTO personnel, etc.)
- An indication whether or not an exhibit was shown or a demonstration conducted
- An identification of the specific prior art discussed
- An indication whether an agreement was reached and if so, a description of the general nature of the agreement (may be by attachment of a copy of amendments or claims agreed as being allowable). Note: Agreement as to allowability is tentative and does not restrict further action by the examiner to the contrary.
- The signature of the examiner who conducted the interview (if Form is not an attachment to a signed Office action)

It is desirable that the examiner orally remind the applicant of his or her obligation to record the substance of the interview of each case It should be noted, however, that the Interview Summary Form will not normally be considered a complete and proper recordation of the interview unless it includes, or is supplemented by the applicant or the examiner to include, all of the applicable items required below concerning the substance of the interview.

A complete and proper recordation of the substance of any interview should include at least the following applicable items.
1) A brief description of the nature of any exhibit shown or any demonstration conducted,
2) an identification of the claims discussed,
3) an identification of the specific prior art discussed,
4) an identification of the principal proposed amendments of a substantive nature discussed, unless these are already described on the Interview Summary Form completed by the Examiner,
5) a brief identification of the general thrust of the principal arguments presented to the examiner,
   (The identification of arguments need not be lengthy or elaborate A verbatim or highly detailed description of the arguments is not required. The identification of the arguments is sufficient if the general nature or thrust of the principal arguments made to the examiner can be understood in the context of the application file. Of course, the applicant may desire to emphasize and fully describe those arguments which he or she feels were or might be persuasive to the examiner.)
6) a general indication of any other pertinent matters discussed, and
7) if appropriate, the general results or outcome of the interview unless already described in the Interview Summary Form completed by the examiner

Examiners are expected to carefully review the applicant's record of the substance of an interview. If the record is not complete and accurate, the examiner will give the applicant an extendable one month time period to correct the record.

Examiner to Check for Accuracy

If the claims are allowable for other reasons of record, the examiner should send a letter setting forth the examiner's version of the statement attributed to him or her. If the record is complete and accurate, the examiner should place the indication, "Interview Record OK" on the paper recording the substance of the interview along with the date and the examiner's initials.

EXHIBIT 11

US006414950B1

(12) **United States Patent**
Rai et al.

(10) **Patent No.: US 6,414,950 B1**
(45) **Date of Patent: Jul. 2, 2002**

(54) **SEQUENCE DELIVERY OF MESSAGES**

(75) Inventors: **Girish Rai**, Bartlett; **Philip M. Parsons**, Lisle, both of IL (US); **Mooi Chuah**, Eatontown, NJ (US)

(73) Assignee: **Lucent Technologies Inc.**, Murray Hill, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/138,680**

(22) Filed: **Aug. 24, 1998**

Related U.S. Application Data

(60) Provisional application No. 60/061,915, filed on Oct. 14, 1997.

(51) **Int. Cl.**[7] **H04L 12/64**
(52) **U.S. Cl.** **370/338**; 370/352
(58) **Field of Search** 370/338, 352–356

(56) **References Cited**

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2001/0036184 A1 * 11/2001 Kinoshita et al. 370/389
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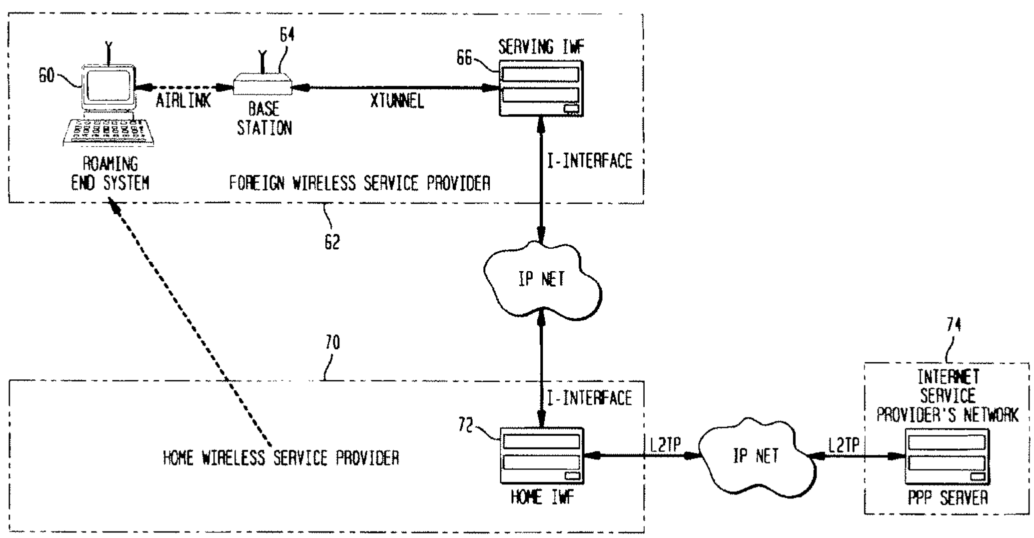
* cited by examiner

Primary Examiner—Melvin Marcelo

(57) **ABSTRACT**

A coupled data network which ensures in sequence delivery of messages is disclosed. The copuled data network includes a foreign network and a home network. The foreign network includes a foreign mobile switching center and a base station, the base station including an access hub with a serving inter-working function. The home network includes a home mobile switching center, the home mobile switching center including a home inter-working function. A roaming end system is a subscriber to the home network and operates within the foreign network, a message being transportable between the roaming end system and the home inter-working function through the serving inter-working function using a protocol that ensures in sequence delivery of data packets.

60 Claims, 31 Drawing Sheets



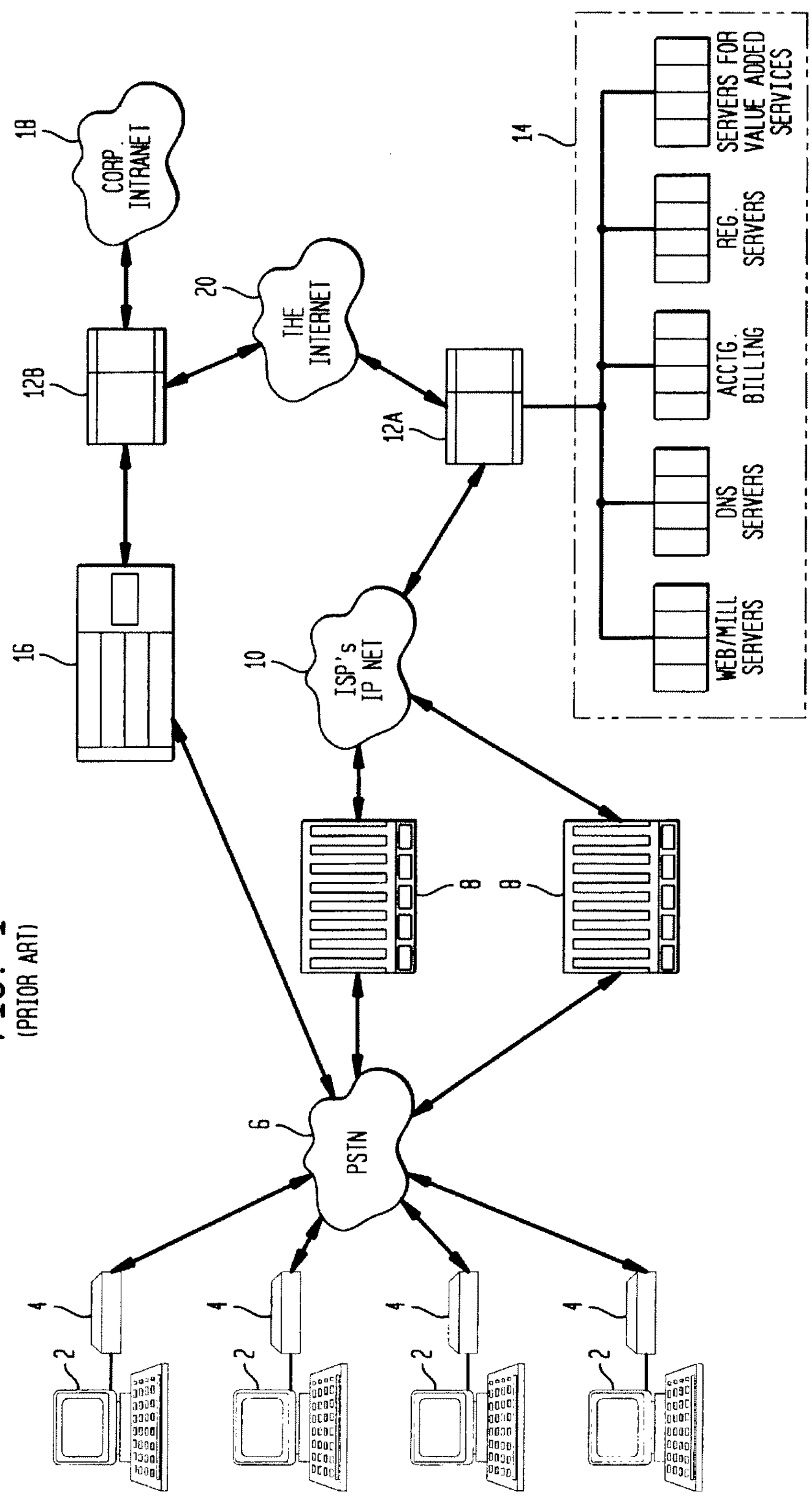
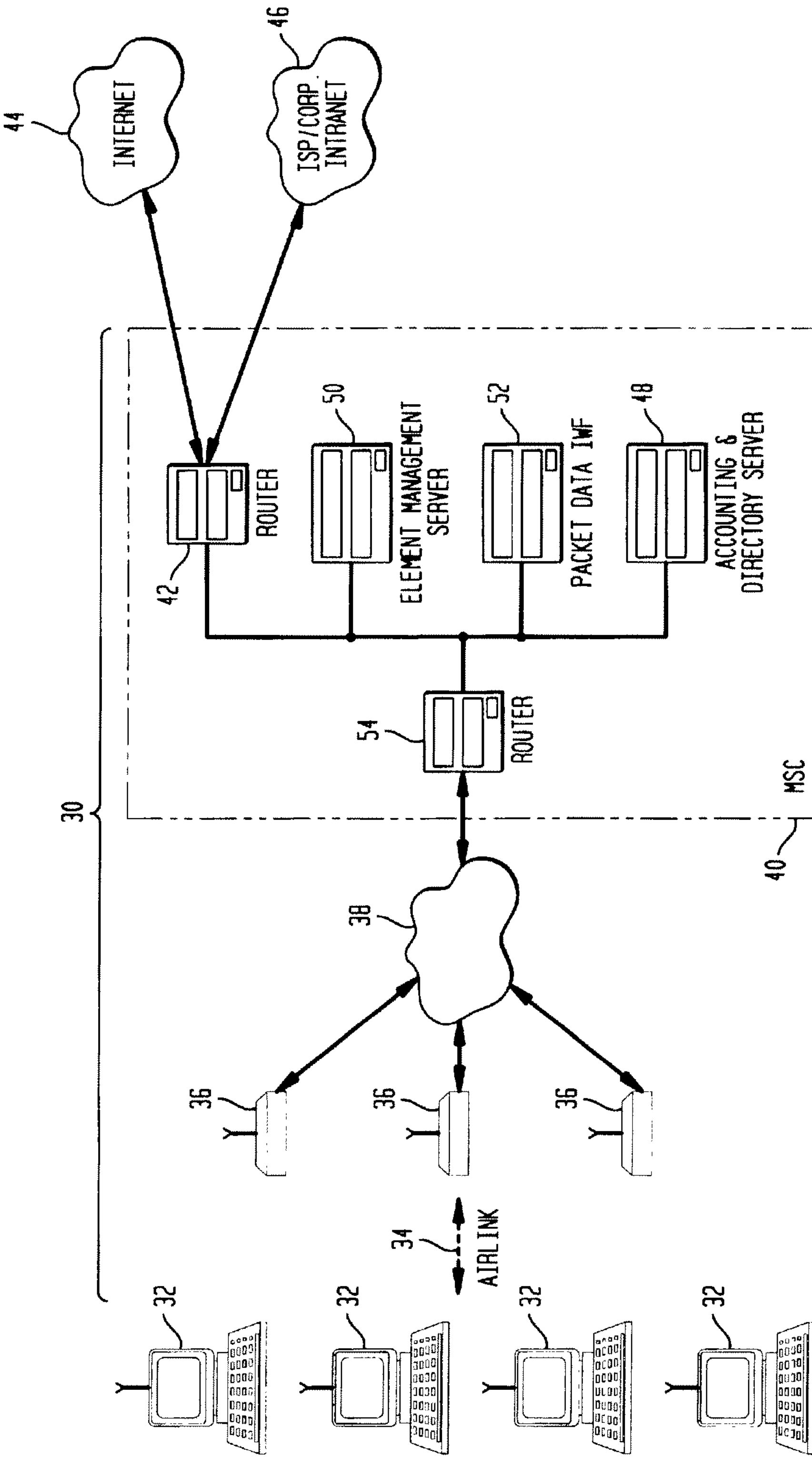


FIG. 1
(PRIOR ART)

FIG. 2



44
INTERNET
46
ISP/CORP. INTRANET
42
ROUTER
50
ELEMENT MANAGEMENT SERVER
52
PACKET DATA IWF
48
ACCOUNTING & DIRECTORY SERVER
54
ROUTER
MSC
40
30
38
36
36
36
34
AIRLINK
32
32
32
32

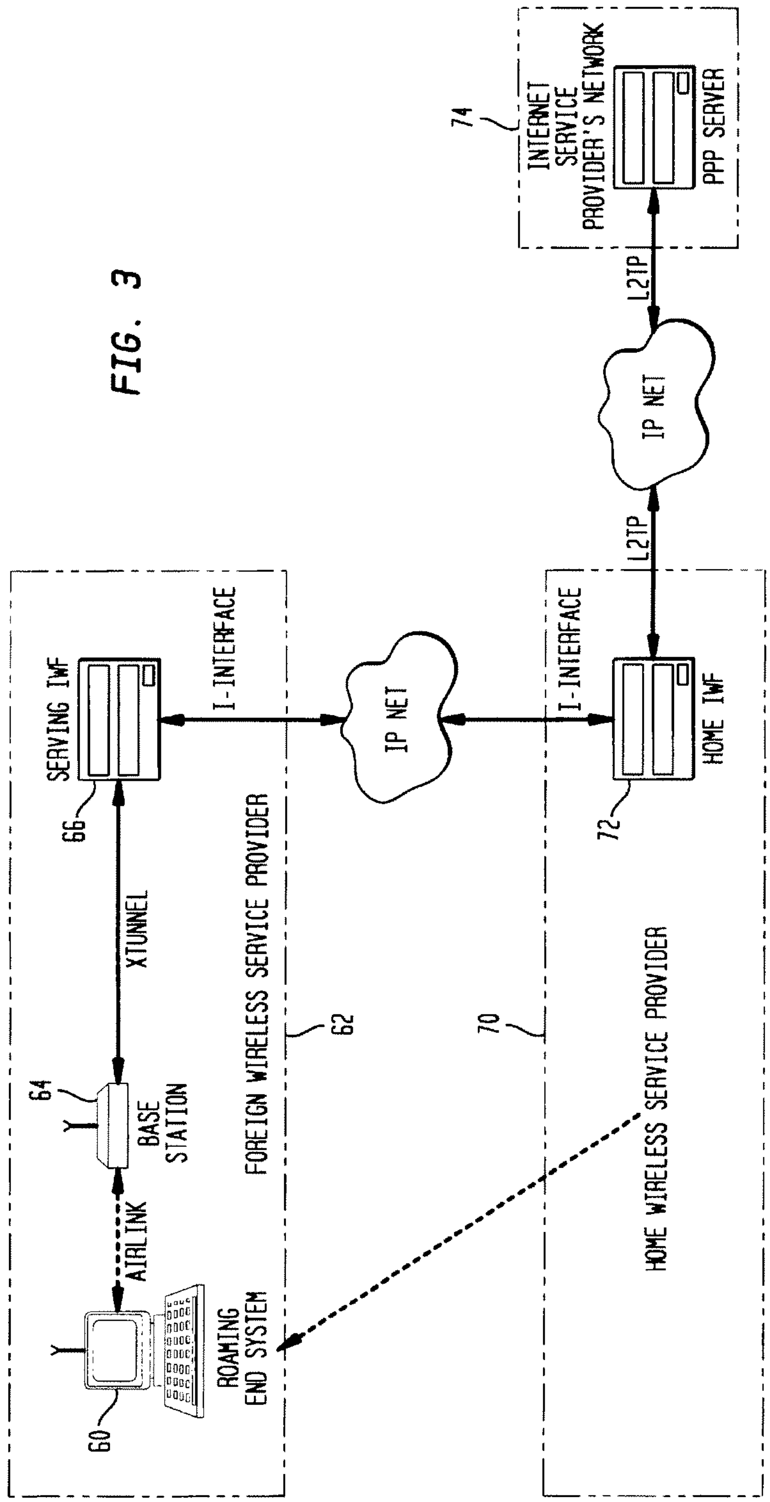
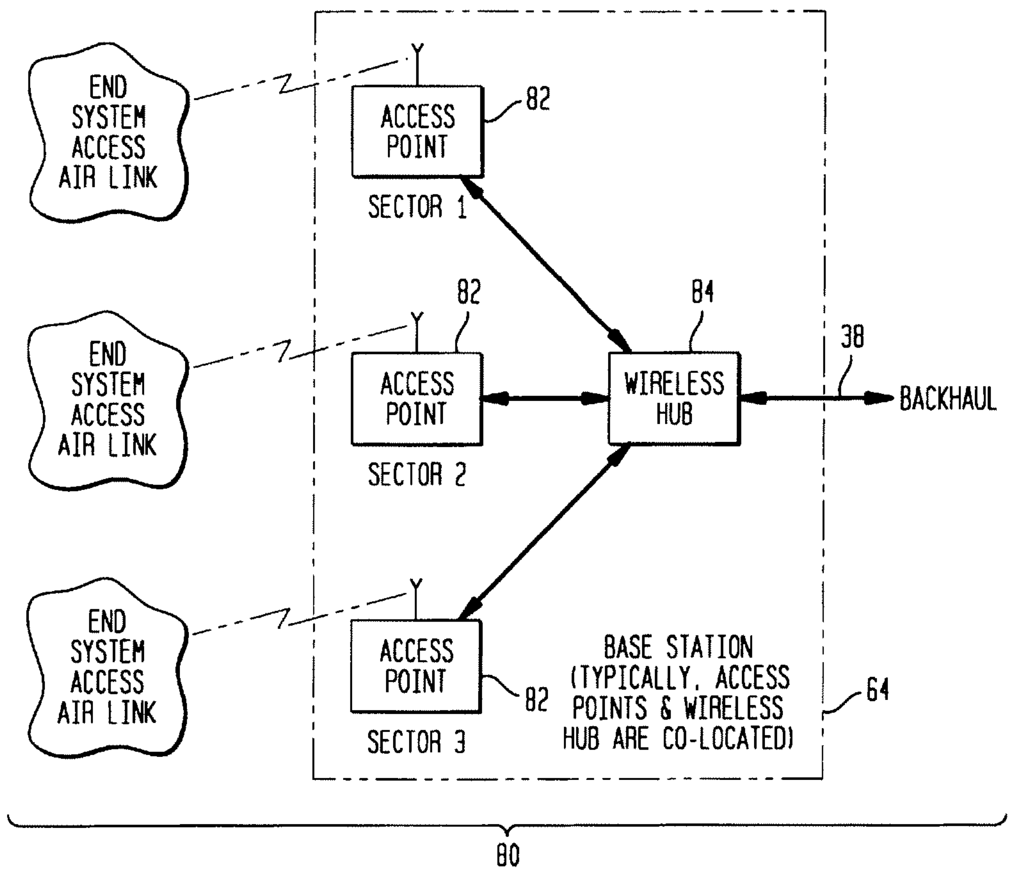

74
INTERNET SERVICE PROVIDER'S NETWORK
PPP SERVER
L2TP
IP NET
L2TP
I-INTERFACE
HOME IWF
72
IP NET
I-INTERFACE
SERVING IWF
66
XTUNNEL
FOREIGN WIRELESS SERVICE PROVIDER
62
70
HOME WIRELESS SERVICE PROVIDER
64
BASE STATION
AIRLINK
ROAMING END SYSTEM
60

FIG. 3

FIG. 4



END SYSTEM ACCESS AIR LINK
END SYSTEM ACCESS AIR LINK
END SYSTEM ACCESS AIR LINK
ACCESS POINT
82
SECTOR 1
82
ACCESS POINT
SECTOR 2
84
WIRELESS HUB
38
BACKHAUL
ACCESS POINT
82
SECTOR 3
BASE STATION (TYPICALLY, ACCESS POINTS & WIRELESS HUB ARE CO-LOCATED)
64
80

FIG. 5

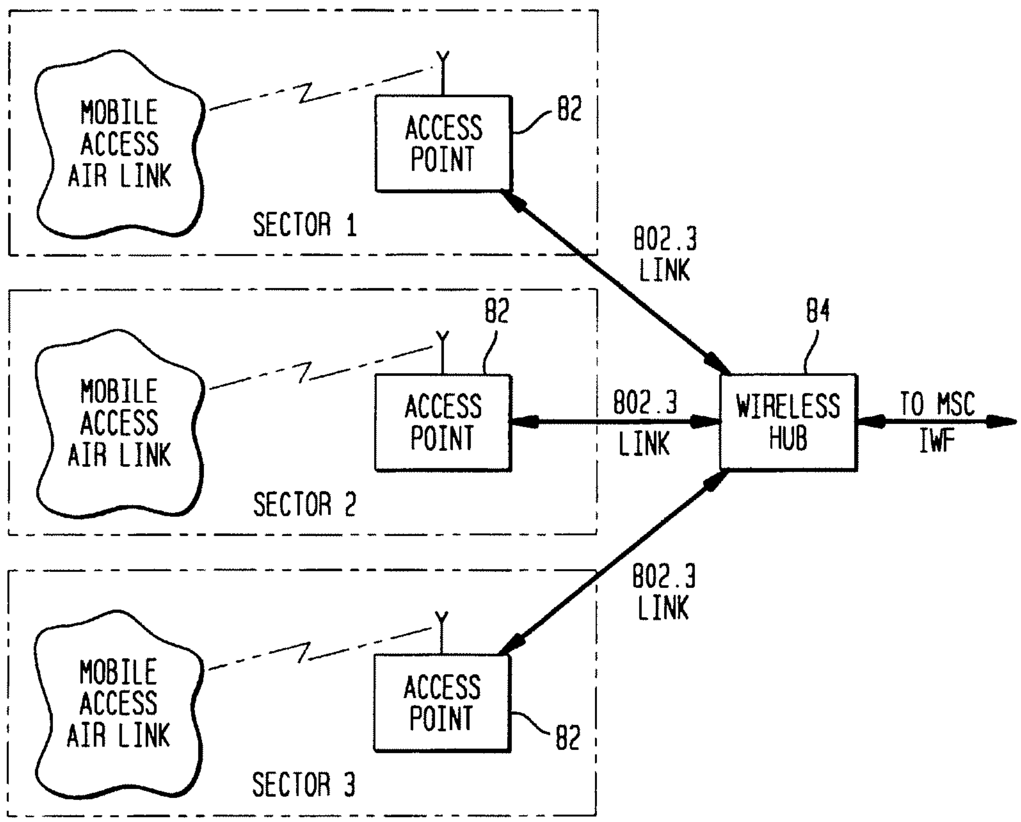
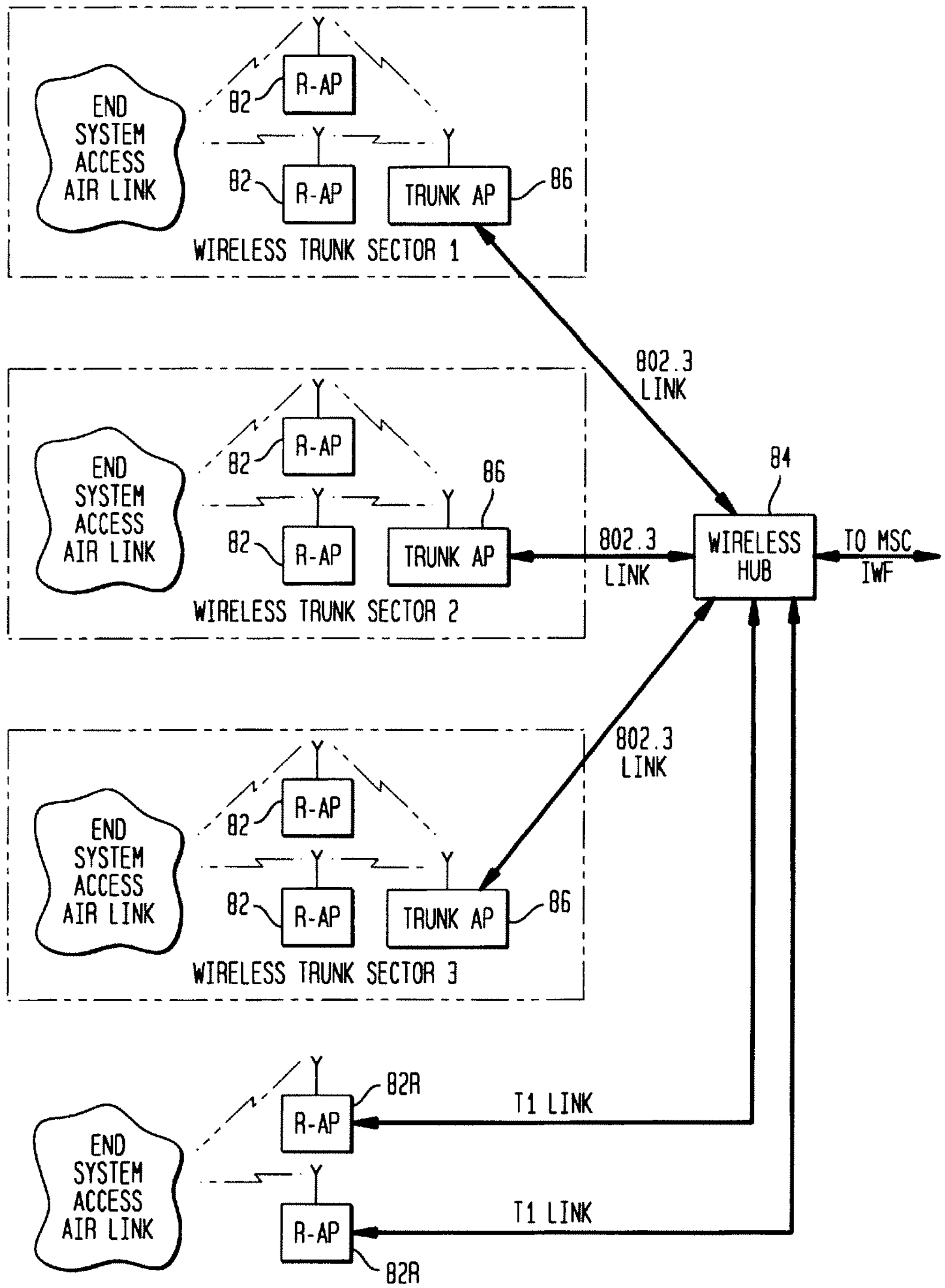

MOBILE
ACCESS
AIR LINK
ACCESS
POINT
82
SECTOR 1
802.3
LINK
82
MOBILE
ACCESS
AIR LINK
ACCESS
POINT
SECTOR 2
802.3
LINK
84
WIRELESS
HUB
TO MSC
IWF
802.3
LINK
MOBILE
ACCESS
AIR LINK
ACCESS
POINT
82
SECTOR 3

FIG. 6



END SYSTEM ACCESS AIR LINK
R-AP
82
TRUNK AP
86
WIRELESS TRUNK SECTOR 1
802.3 LINK
WIRELESS TRUNK SECTOR 2
84
WIRELESS HUB
TO MSC IWF
WIRELESS TRUNK SECTOR 3
82R
T1 LINK

FIG. 7

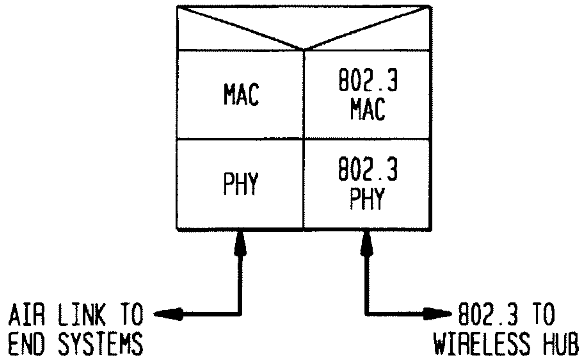


FIG. 8

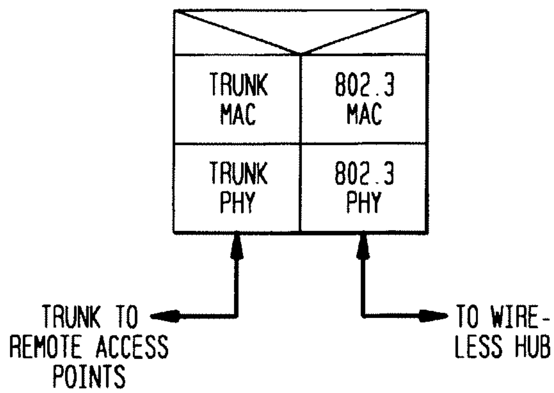


FIG. 9

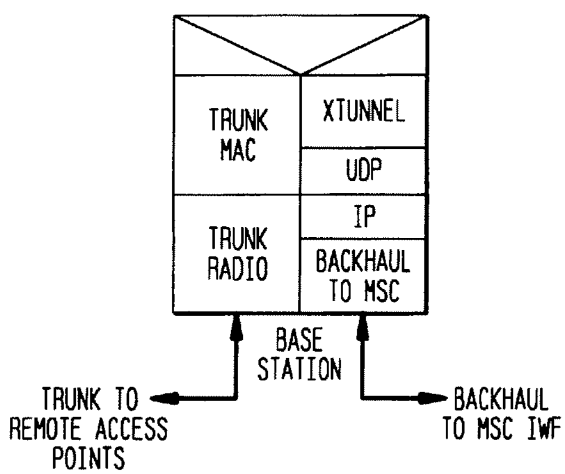


FIG. 10

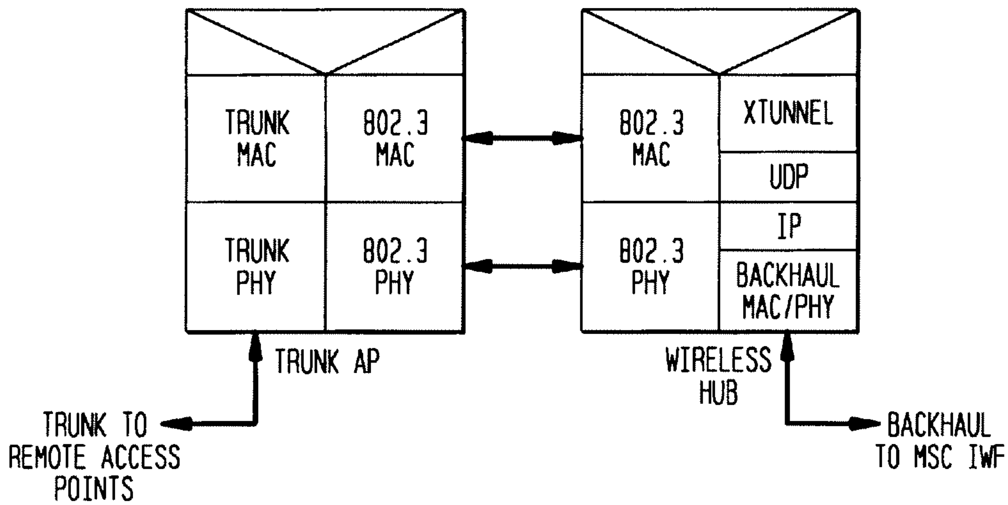
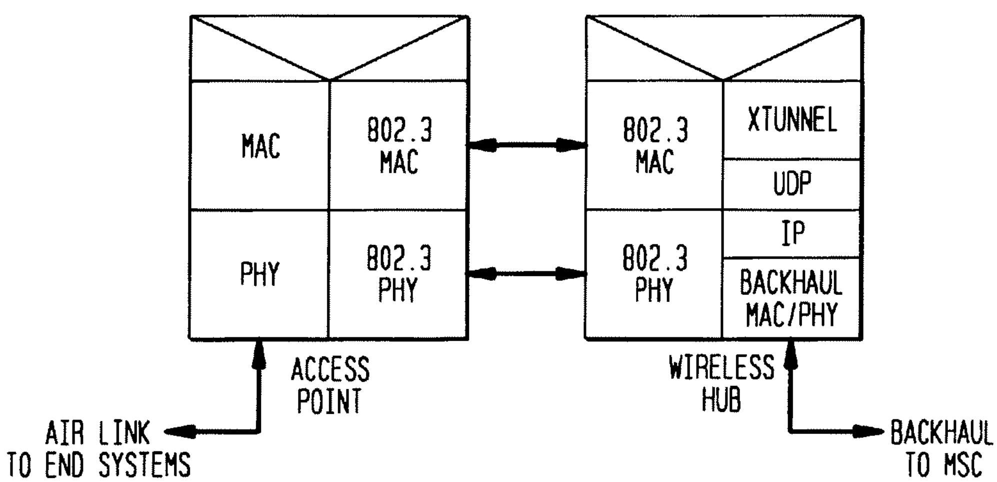

TRUNK
MAC
802.3
MAC
TRUNK
PHY
802.3
PHY
802.3
MAC
XTUNNEL
UDP
802.3
PHY
IP
BACKHAUL
MAC/PHY
TRUNK AP
WIRELESS
HUB
TRUNK TO
REMOTE ACCESS
POINTS
BACKHAUL
TO MSC IWF

FIG. 11


MAC
802.3
MAC
PHY
802.3
PHY
802.3
MAC
XTUNNEL
UDP
802.3
PHY
IP
BACKHAUL
MAC/PHY
ACCESS
POINT
WIRELESS
HUB
AIR LINK
TO END SYSTEMS
BACKHAUL
TO MSC

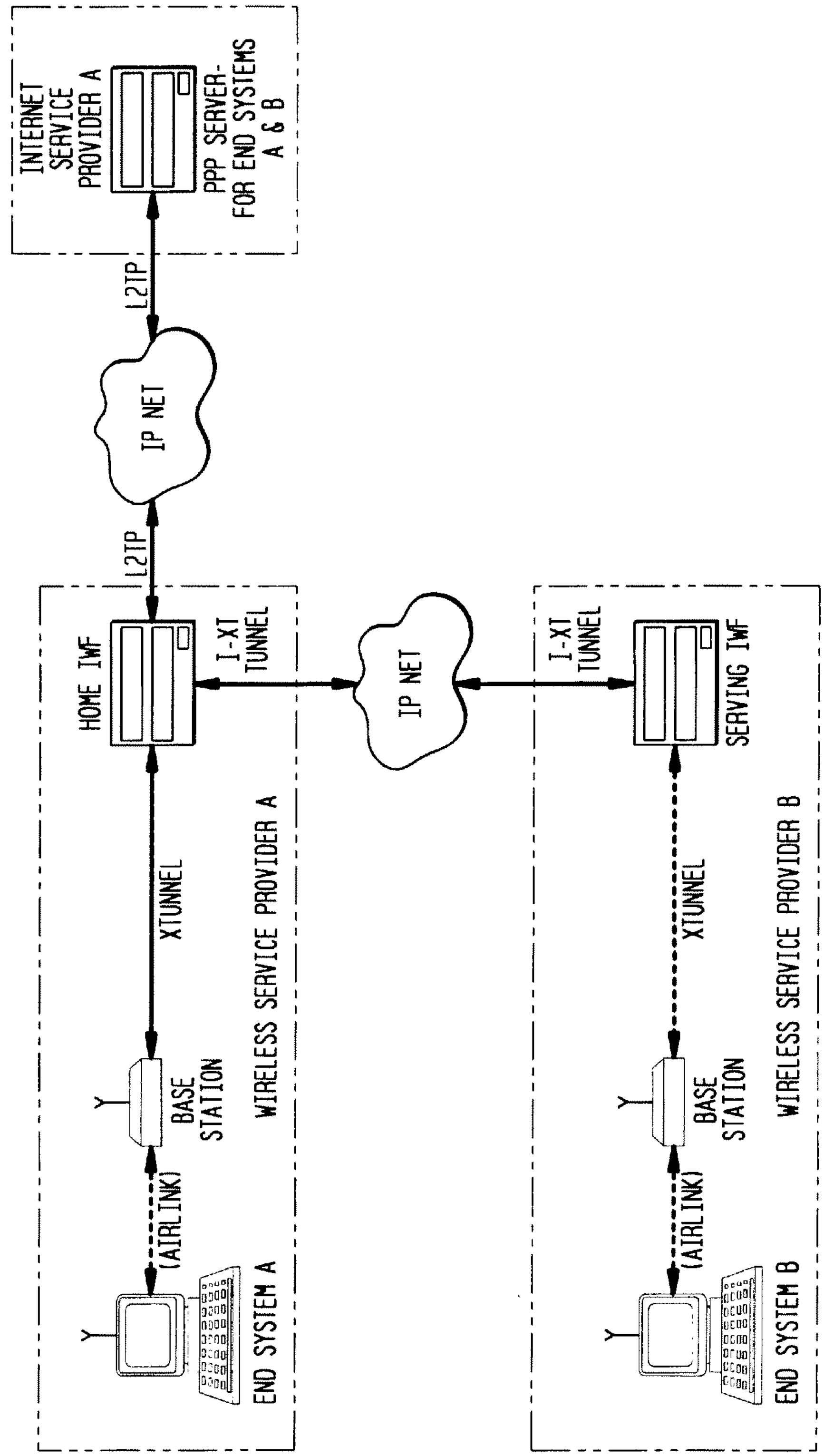

INTERNET
SERVICE
PROVIDER A
PPP SERVER-
FOR END SYSTEMS
A & B
L2TP
IP NET
L2TP
HOME IWF
I-XT
TUNNEL
IP NET
I-XT
TUNNEL
SERVING IWF
XTUNNEL
BASE
STATION
WIRELESS SERVICE PROVIDER A
(AIRLINK)
END SYSTEM A
XTUNNEL
BASE
STATION
WIRELESS SERVICE PROVIDER B
(AIRLINK)
END SYSTEM B

FIG. 12

FIG. 13

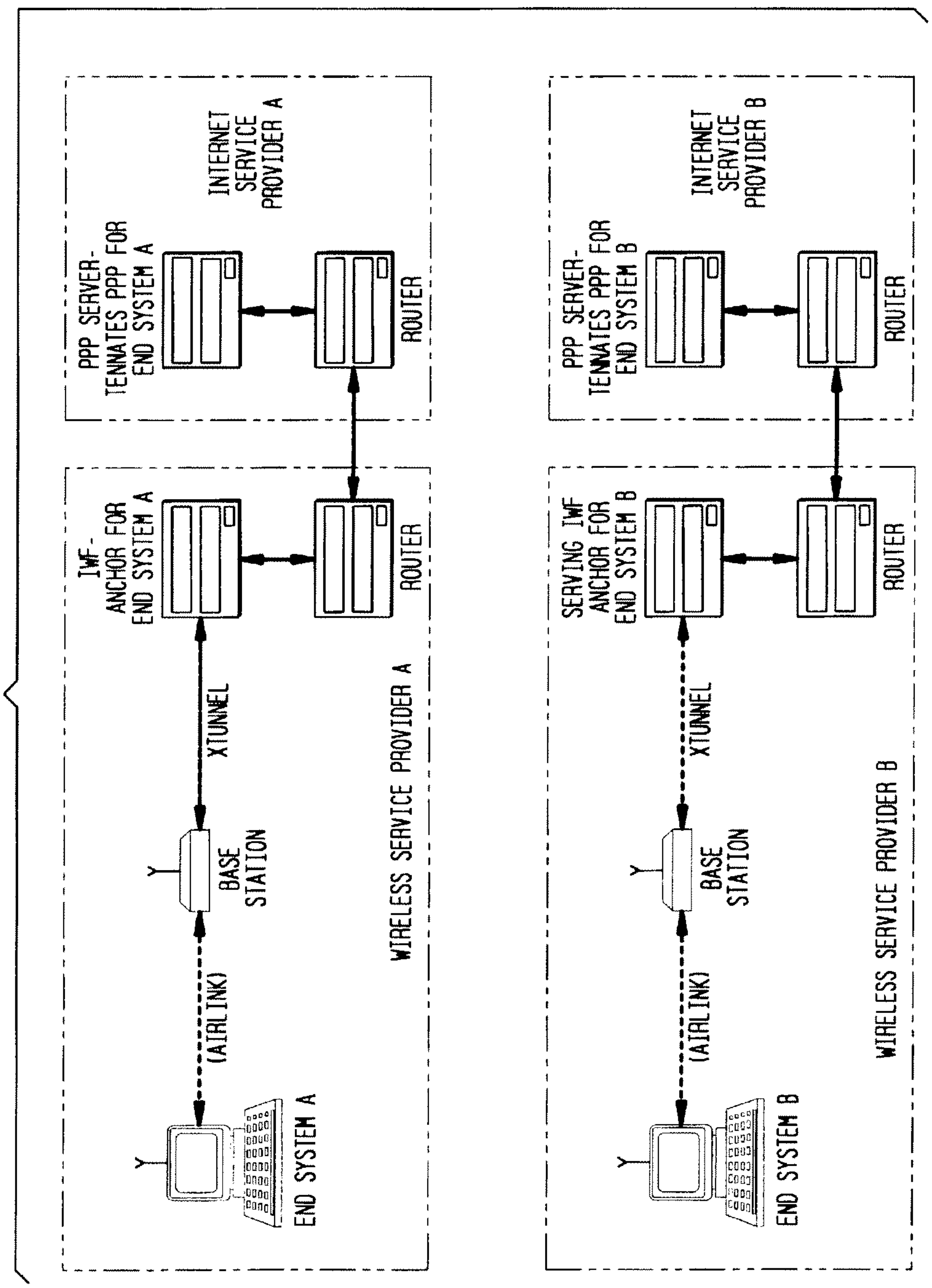
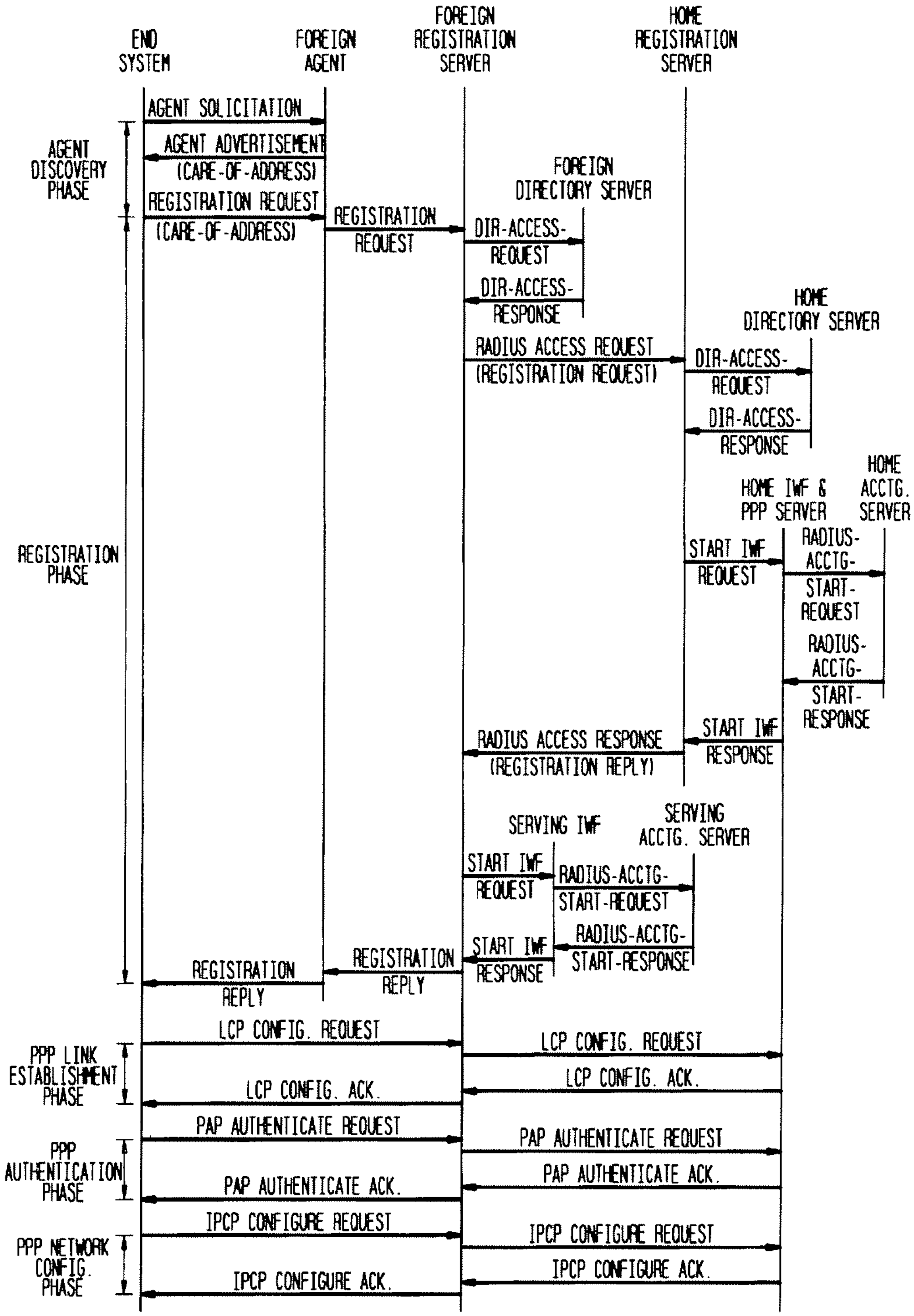

PPP SERVER-
TENNATES PPP FOR
END SYSTEM A
INTERNET
SERVICE
PROVIDER A
ROUTER
IWF-
ANCHOR FOR
END SYSTEM A
ROUTER
XTUNNEL
BASE
STATION
(AIRLINK)
END SYSTEM A
WIRELESS SERVICE PROVIDER A
PPP SERVER-
TENNATES PPP FOR
END SYSTEM B
INTERNET
SERVICE
PROVIDER B
ROUTER
SERVING IWF
ANCHOR FOR
END SYSTEM B
ROUTER
XTUNNEL
BASE
STATION
(AIRLINK)
END SYSTEM B
WIRELESS SERVICE PROVIDER B

FIG. 14


END SYSTEM
FOREIGN AGENT
FOREIGN REGISTRATION SERVER
HOME REGISTRATION SERVER
AGENT DISCOVERY PHASE
AGENT SOLICITATION
AGENT ADVERTISEMENT (CARE-OF-ADDRESS)
REGISTRATION REQUEST (CARE-OF-ADDRESS)
REGISTRATION REQUEST
FOREIGN DIRECTORY SERVER
DIR-ACCESS-REQUEST
DIR-ACCESS-RESPONSE
HOME DIRECTORY SERVER
RADIUS ACCESS REQUEST (REGISTRATION REQUEST)
DIR-ACCESS-REQUEST
DIR-ACCESS-RESPONSE
REGISTRATION PHASE
HOME IWF & PPP SERVER
HOME ACCTG. SERVER
START IWF REQUEST
RADIUS-ACCTG-START-REQUEST
RADIUS-ACCTG-START-RESPONSE
START IWF RESPONSE
RADIUS ACCESS RESPONSE (REGISTRATION REPLY)
SERVING IWF
SERVING ACCTG. SERVER
START IWF REQUEST
RADIUS-ACCTG-START-REQUEST
RADIUS-ACCTG-START-RESPONSE
START IWF RESPONSE
REGISTRATION REPLY
REGISTRATION REPLY
PPP LINK ESTABLISHMENT PHASE
LCP CONFIG. REQUEST
LCP CONFIG. REQUEST
LCP CONFIG. ACK.
LCP CONFIG. ACK.
PPP AUTHENTICATION PHASE
PAP AUTHENTICATE REQUEST
PAP AUTHENTICATE REQUEST
PAP AUTHENTICATE ACK.
PAP AUTHENTICATE ACK.
PPP NETWORK CONFIG. PHASE
IPCP CONFIGURE REQUEST
IPCP CONFIGURE REQUEST
IPCP CONFIGURE ACK.
IPCP CONFIGURE ACK.

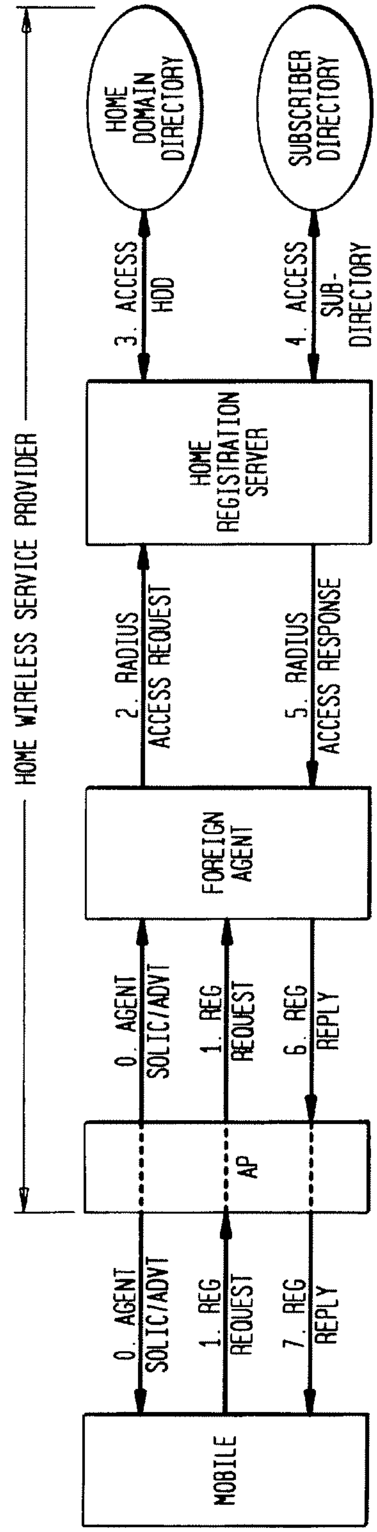

HOME WIRELESS SERVICE PROVIDER
HOME DOMAIN DIRECTORY
SUBSCRIBER DIRECTORY
3. ACCESS HDD
4. ACCESS SUB-DIRECTORY
HOME REGISTRATION SERVER
2. RADIUS ACCESS REQUEST
5. RADIUS ACCESS RESPONSE
FOREIGN AGENT
0. AGENT SOLIC/ADVT
1. REG REQUEST
6. REG REPLY
AP
0. AGENT SOLIC/ADVT
1. REG REQUEST
7. REG REPLY
MOBILE

FIG. 15

FIG. 16

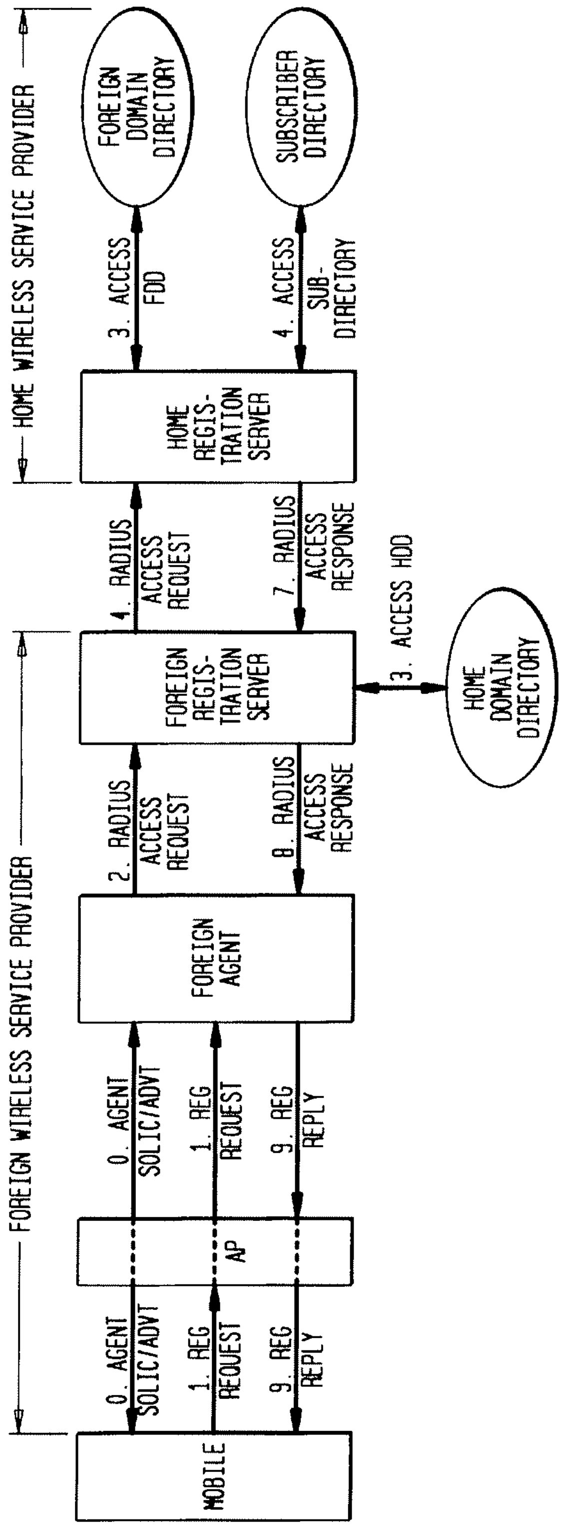

HOME WIRELESS SERVICE PROVIDER
FOREIGN DOMAIN DIRECTORY
SUBSCRIBER DIRECTORY
3. ACCESS FDD
4. ACCESS SUB-DIRECTORY
HOME REGIS-TRATION SERVER
4. RADIUS ACCESS REQUEST
7. RADIUS ACCESS RESPONSE
3. ACCESS HDD
HOME DOMAIN DIRECTORY
FOREIGN WIRELESS SERVICE PROVIDER
FOREIGN REGIS-TRATION SERVER
2. RADIUS ACCESS REQUEST
8. RADIUS ACCESS RESPONSE
FOREIGN AGENT
0. AGENT SOLIC/ADVT
1. REG REQUEST
9. REG REPLY
AP
0. AGENT SOLIC/ADVT
1. REG REQUEST
9. REG REPLY
MOBILE

FIG. 17

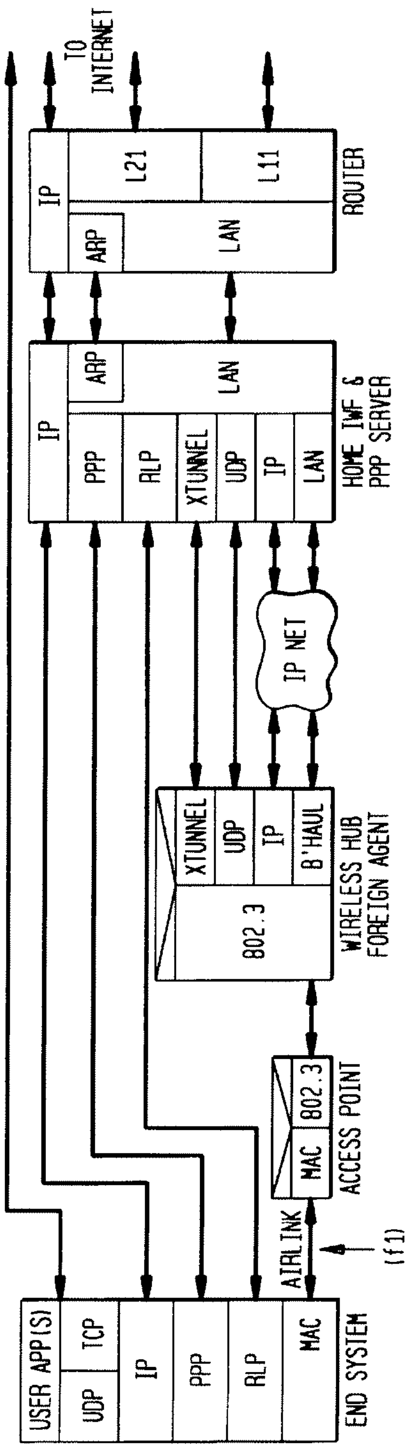
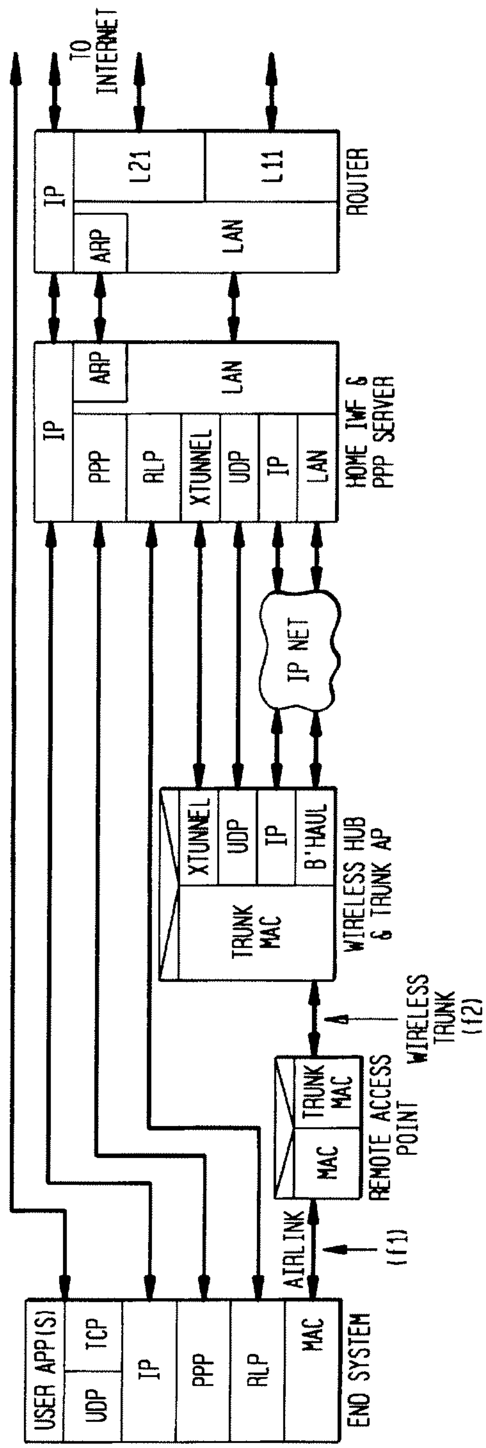

TO INTERNET
IP
L21
L11
ARP
LAN
ROUTER
IP
ARP
LAN
PPP
RLP
XTUNNEL
UDP
IP
LAN
HOME IWF & PPP SERVER
IP NET
XTUNNEL
UDP
IP
B'HAUL
802.3
WIRELESS HUB FOREIGN AGENT
MAC
802.3
ACCESS POINT
AIRLINK
(f1)
USER APP(S)
UDP
TCP
IP
PPP
RLP
MAC
END SYSTEM

FIG. 18


TO INTERNET
IP
L21
L11
ARP
LAN
ROUTER
IP
ARP
LAN
PPP
RLP
XTUNNEL
UDP
IP
LAN
HOME IWF & PPP SERVER
IP NET
XTUNNEL
UDP
IP
B'HAUL
TRUNK MAC
WIRELESS HUB & TRUNK AP
WIRELESS TRUNK (f2)
MAC
TRUNK MAC
REMOTE ACCESS POINT
AIRLINK
(f1)
USER APP(S)
UDP
TCP
IP
PPP
RLP
MAC
END SYSTEM

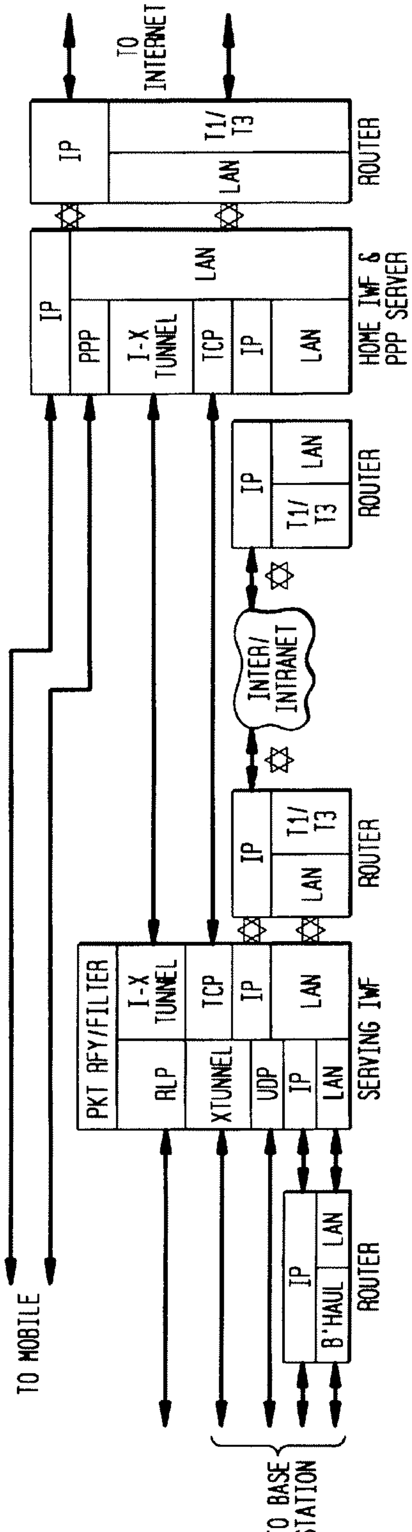
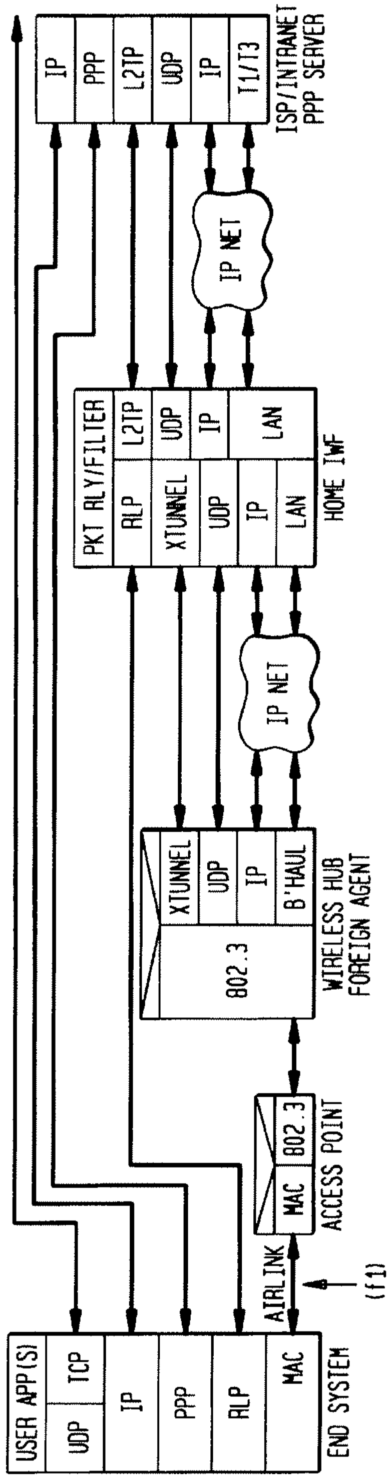

TO INTERNET
IP
T1/ T3
LAN
ROUTER
IP
LAN
PPP
I-X TUNNEL
TCP
IP
LAN
HOME IWF & PPP SERVER
IP
LAN
T1/ T3
ROUTER
INTER/ INTRANET
IP
T1/ T3
LAN
ROUTER
PKT RFY/FILTER
I-X TUNNEL
TCP
IP
LAN
RLP
XTUNNEL
UDP
IP
LAN
SERVING IWF
IP
LAN
B'HAUL
ROUTER
TO MOBILE
TO BASE STATION

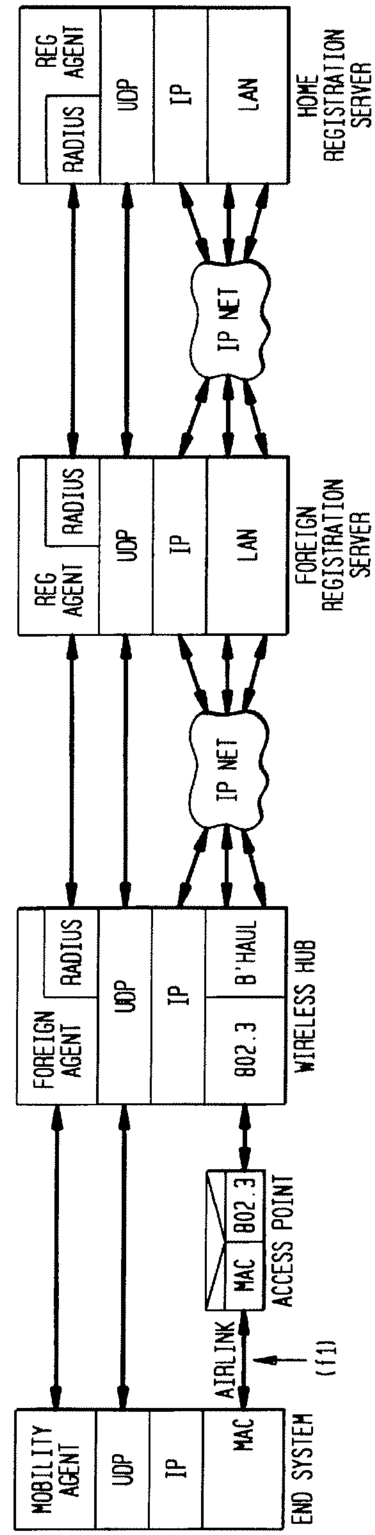
FIG. 19

FIG. 20



USER APP(S)
UDP
TCP
IP
PPP
RLP
MAC
END SYSTEM
AIRLINK
(f1)
MAC
802.3
ACCESS POINT
XTUNNEL
UDP
IP
B'HAUL
802.3
WIRELESS HUB
FOREIGN AGENT
IP NET
PKT RLY/FILTER
RLP
XTUNNEL
UDP
IP
LAN
L2TP
UDP
IP
LAN
HOME IWF
IP NET
IP
PPP
L2TP
UDP
IP
T1/T3
ISP/INTRANET
PPP SERVER

FIG. 21



MOBILITY
AGENT
UDP
IP
MAC
END SYSTEM
AIRLINK
(f1)
MAC
802.3
ACCESS POINT
FOREIGN
AGENT
RADIUS
UDP
IP
B'HAUL
802.3
WIRELESS HUB
IP NET
REG
AGENT
RADIUS
UDP
IP
LAN
FOREIGN
REGISTRATION
SERVER
IP NET
RADIUS
REG
AGENT
UDP
IP
LAN
HOME
REGISTRATION
SERVER

FIG. 22

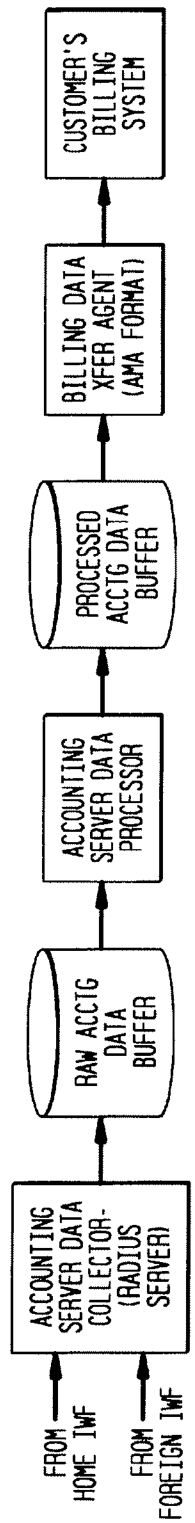
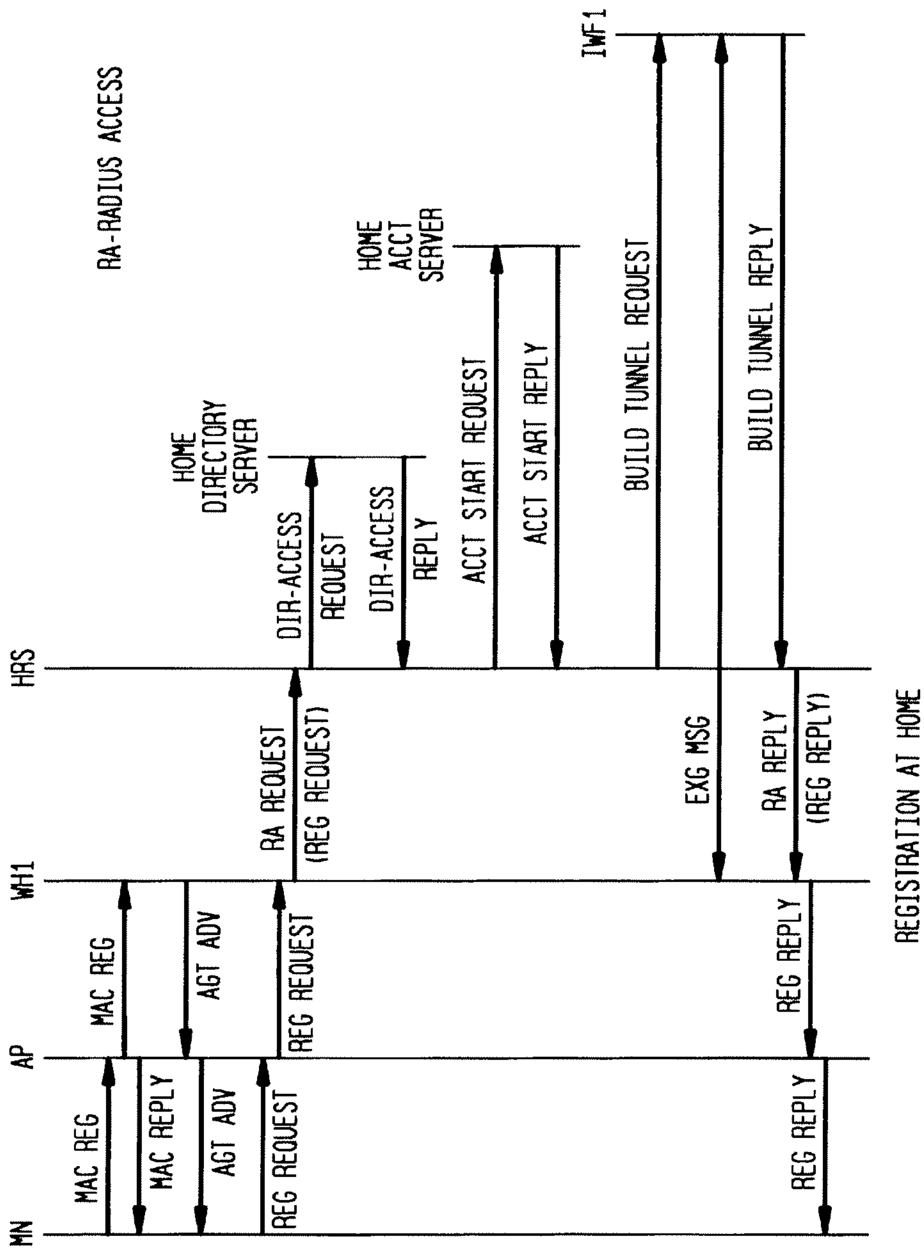

FROM HOME IWF
FROM FOREIGN IWF
ACCOUNTING SERVER DATA COLLECTOR-(RADIUS SERVER)
RAW ACCTG DATA BUFFER
ACCOUNTING SERVER DATA PROCESSOR
PROCESSED ACCTG DATA BUFFER
BILLING DATA XFER AGENT (AMA FORMAT)
CUSTOMER'S BILLING SYSTEM

FIG. 23


RA-RADIUS ACCESS
MN
AP
WH1
HRS
HOME DIRECTORY SERVER
HOME ACCT SERVER
IWF1
MAC REG
MAC REPLY
AGT ADV
REG REQUEST
MAC REG
AGT ADV
REG REQUEST
RA REQUEST (REG REQUEST)
DIR-ACCESS REQUEST
DIR-ACCESS REPLY
ACCT START REQUEST
ACCT START REPLY
BUILD TUNNEL REQUEST
EXG MSG
BUILD TUNNEL REPLY
RA REPLY (REG REPLY)
REG REPLY
REG REPLY
REGISTRATION AT HOME

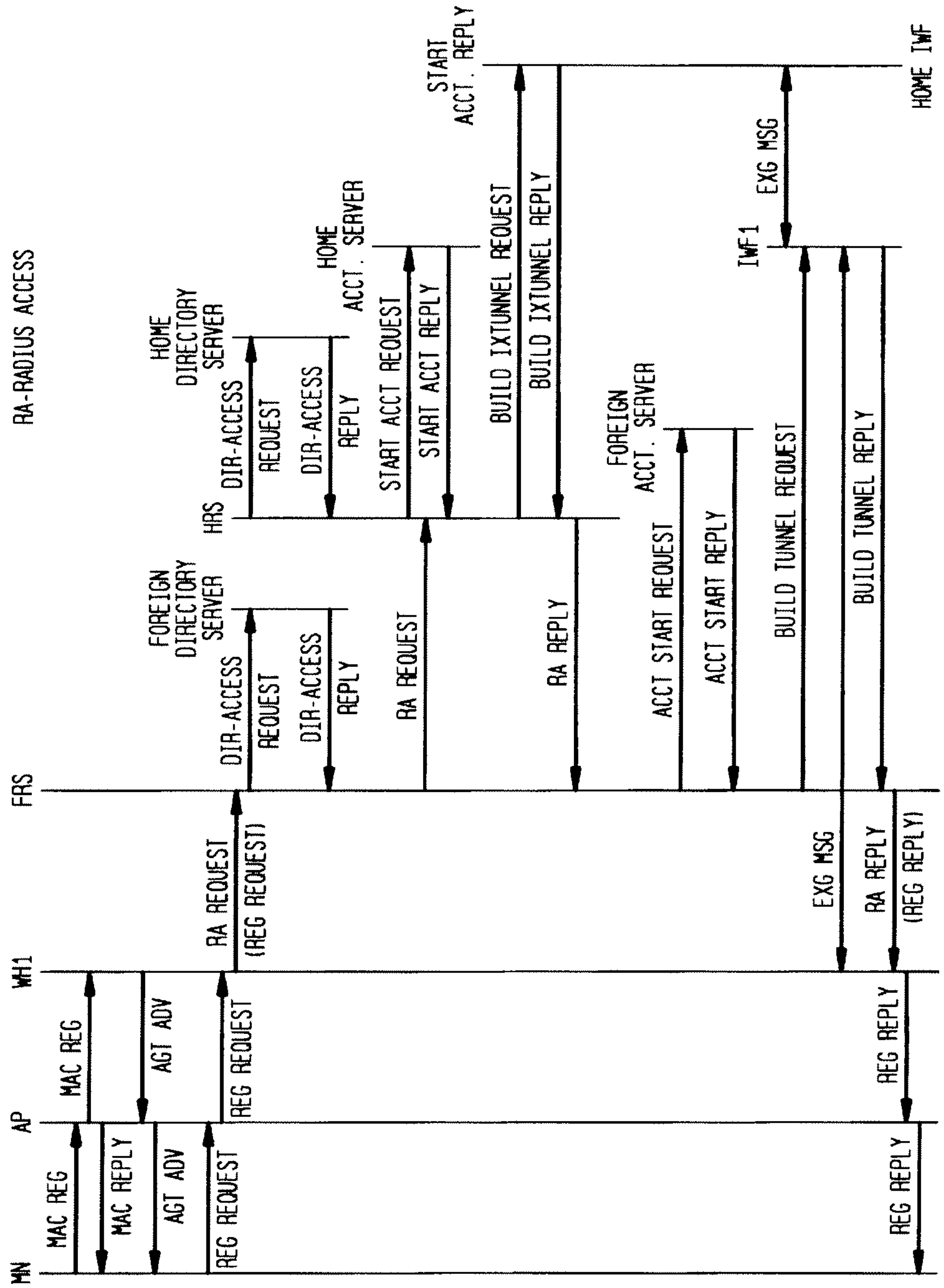

RA-RADIUS ACCESS
MN
AP
WH1
FRS
HRS
FOREIGN DIRECTORY SERVER
HOME DIRECTORY SERVER
HOME ACCT. SERVER
START ACCT. REPLY
FOREIGN ACCT. SERVER
IWF1
HOME IWF
MAC REG
MAC REPLY
AGT ADV
REG REQUEST
RA REQUEST (REG REQUEST)
DIR-ACCESS REQUEST
DIR-ACCESS REPLY
RA REQUEST
START ACCT REQUEST
START ACCT REPLY
BUILD IXTUNNEL REQUEST
BUILD IXTUNNEL REPLY
RA REPLY
ACCT START REQUEST
ACCT START REPLY
BUILD TUNNEL REQUEST
BUILD TUNNEL REPLY
EXG MSG
RA REPLY (REG REPLY)
REG REPLY

FIG. 24

FIG. 25

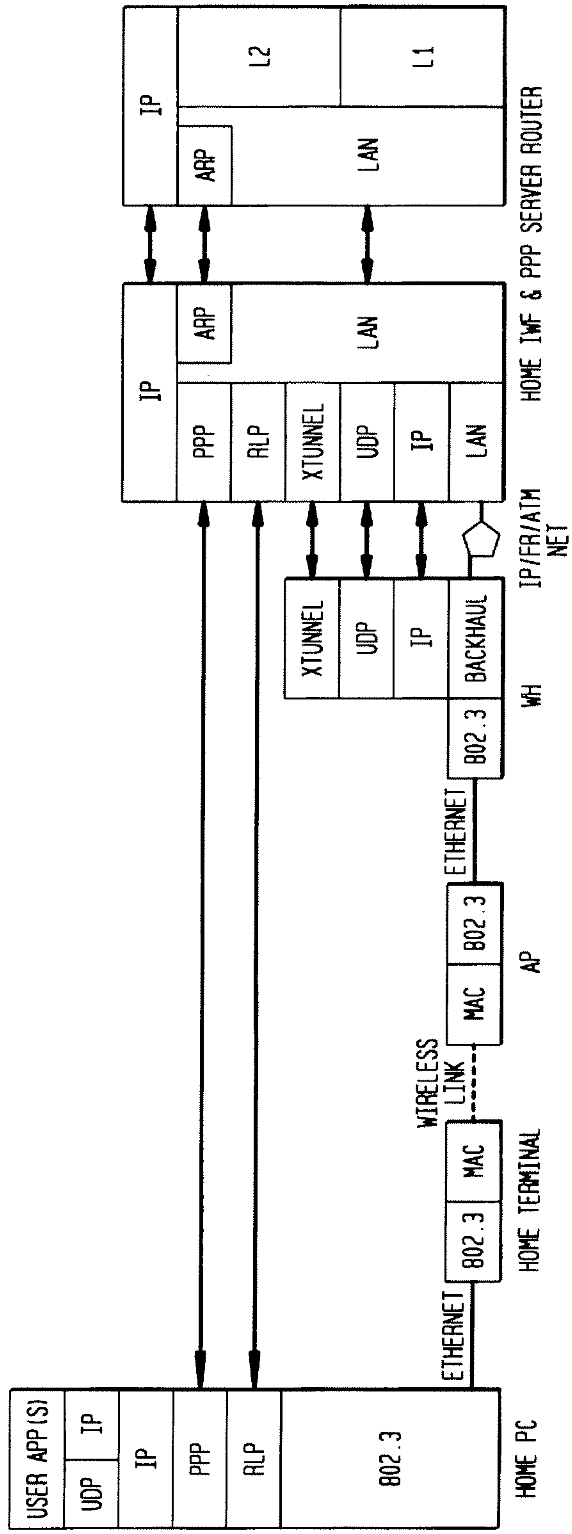
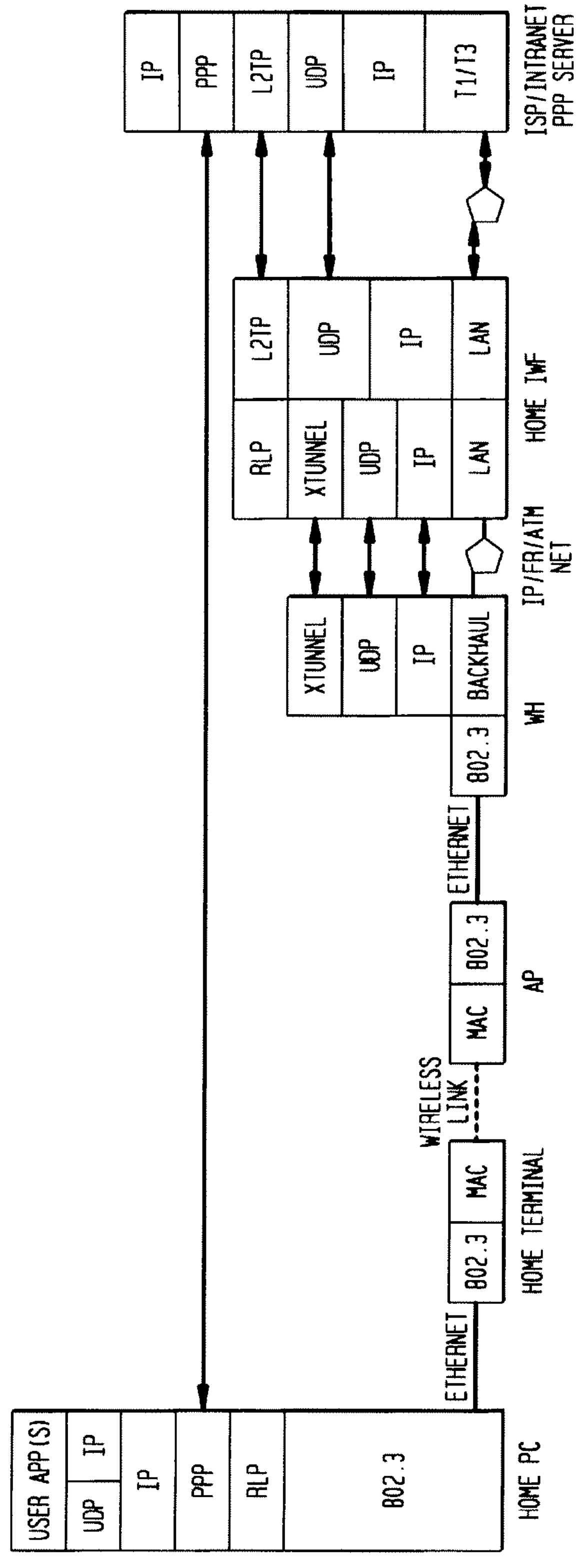
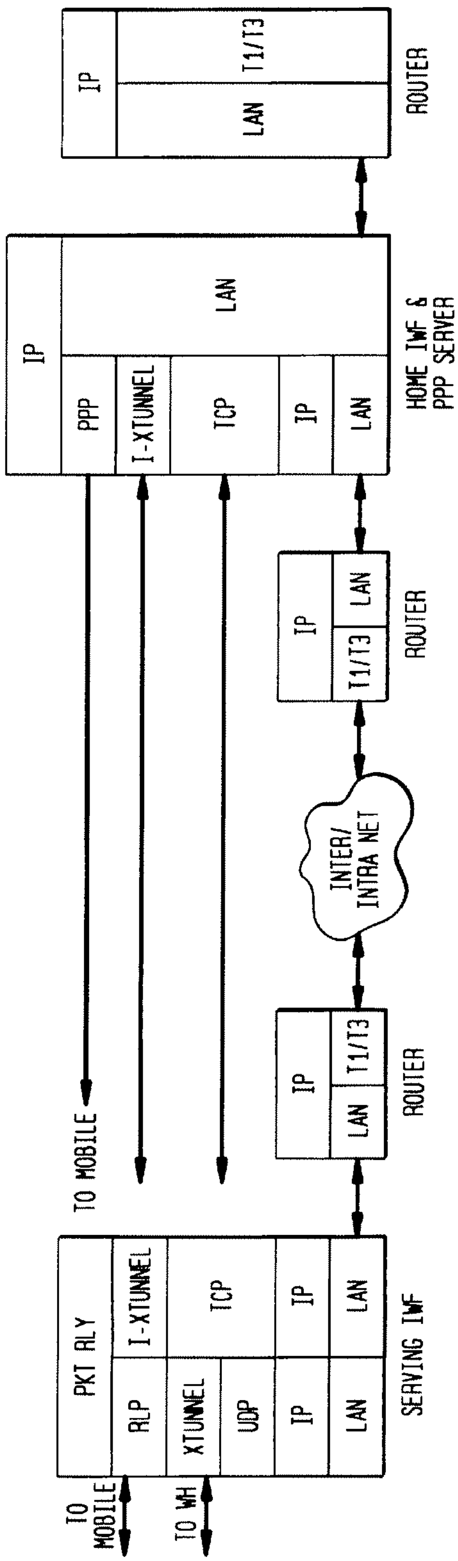

IP
ARP
L2
L1
LAN
HOME IWF & PPP SERVER ROUTER
PPP
RLP
XTUNNEL
UDP
LAN
IP/FR/ATM NET
BACKHAUL
802.3
WH
ETHERNET
MAC
AP
WIRELESS LINK
HOME TERMINAL
USER APP(S)
802.3
HOME PC

FIG. 26



USER APP(S)
UDP
IP
IP
PPP
RLP
802.3
HOME PC
ETHERNET
802.3
MAC
HOME TERMINAL
WIRELESS LINK
MAC
802.3
AP
ETHERNET
802.3
BACKHAUL
IP
UDP
XTUNNEL
WH
IP/FR/ATM NET
LAN
IP
UDP
XTUNNEL
RLP
LAN
IP
UDP
L2TP
HOME IWF
T1/T3
IP
UDP
L2TP
PPP
IP
ISP/INTRANET PPP SERVER

FIG. 27



PROTOCOL STACKS FOR ROAMING MOBILE WHERE HOME IWF IS ALSO A PPP SERVER

FIG. 28

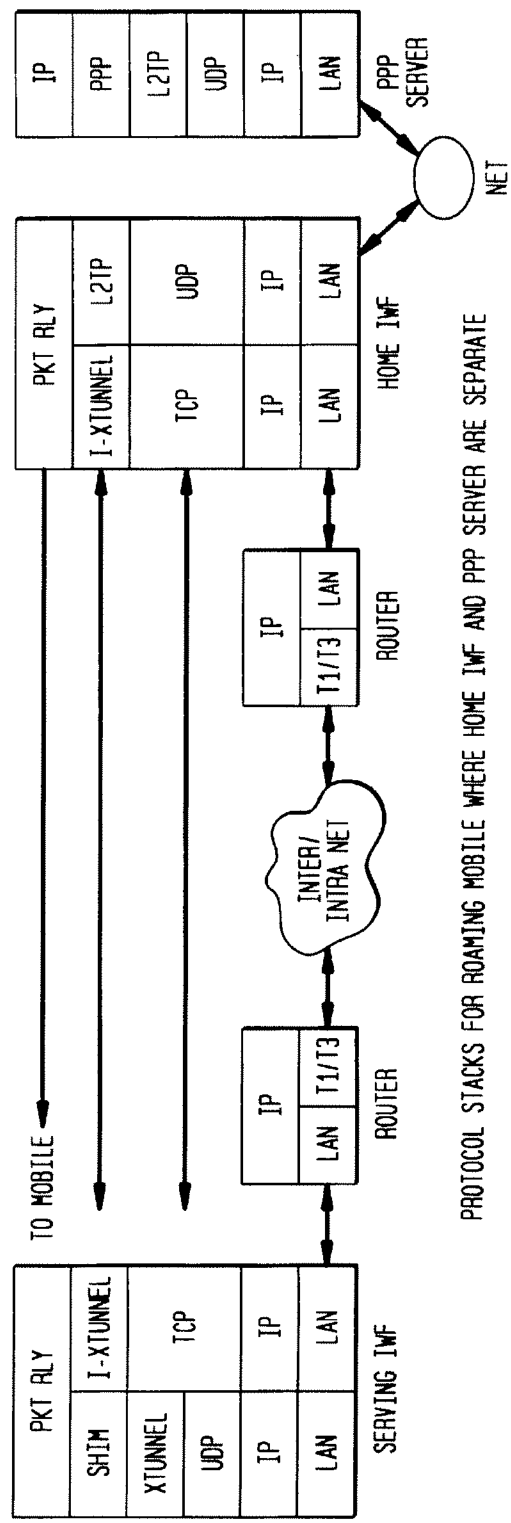

PKT RLY
SHIM
I-XTUNNEL
XTUNNEL
UDP
TCP
IP
IP
LAN
LAN
SERVING IWF
TO MOBILE
IP
LAN
T1/T3
ROUTER
INTER/
INTRA NET
IP
T1/T3
LAN
ROUTER
PKT RLY
I-XTUNNEL
L2TP
TCP
UDP
IP
IP
LAN
LAN
HOME IWF
NET
IP
PPP
L2TP
UDP
IP
LAN
PPP
SERVER
PROTOCOL STACKS FOR ROAMING MOBILE WHERE HOME IWF AND PPP SERVER ARE SEPARATE

FIG. 29

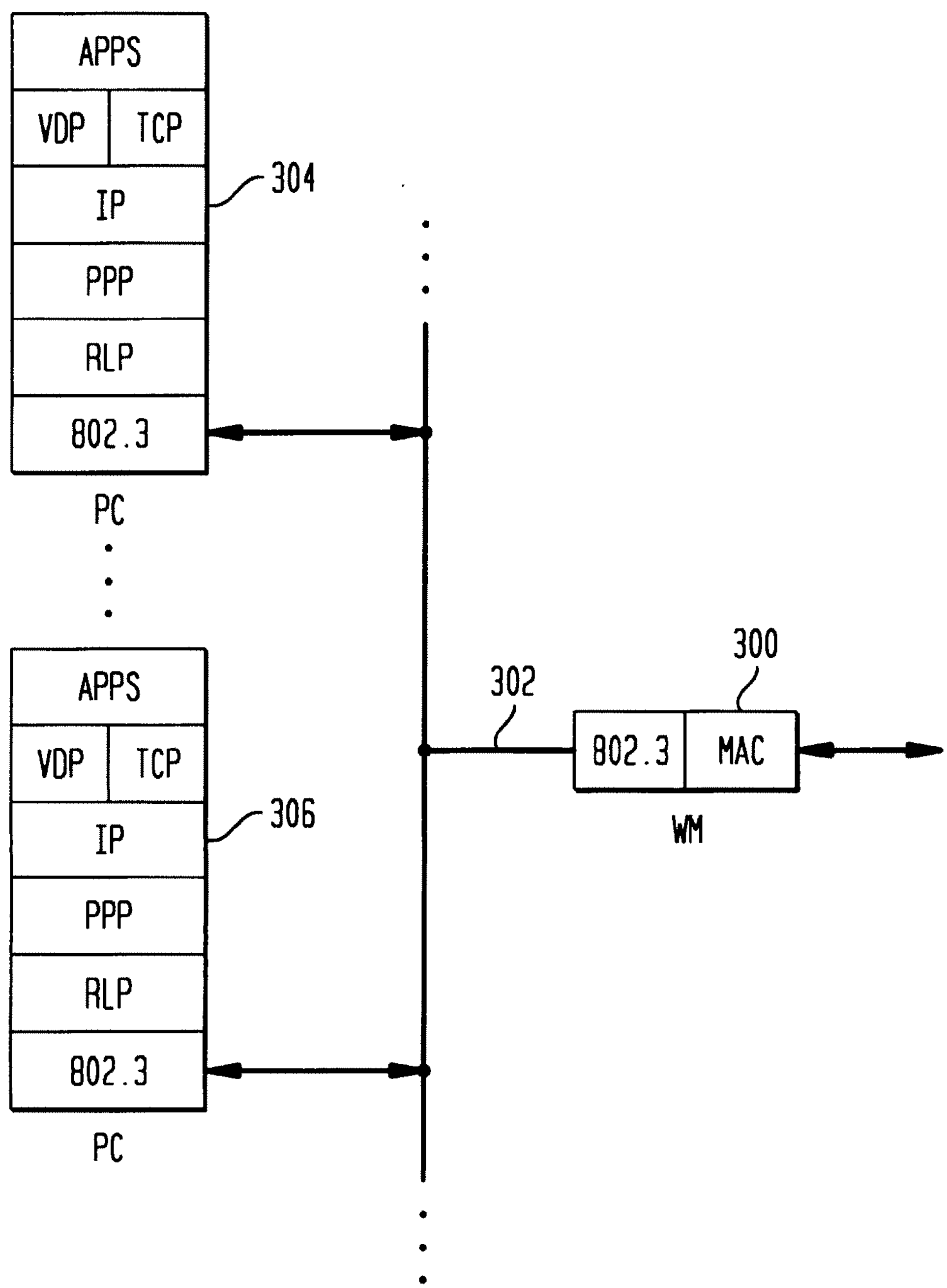

APPS
VDP
TCP
IP
PPP
RLP
802.3
PC
304
APPS
VDP
TCP
IP
PPP
RLP
802.3
PC
306
302
300
802.3
MAC
WM

FIG. 30

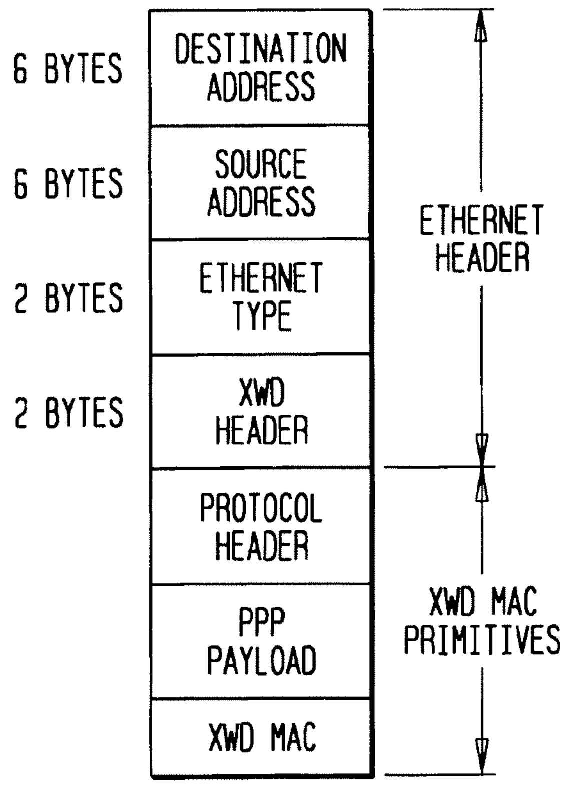

6 BYTES
DESTINATION ADDRESS
6 BYTES
SOURCE ADDRESS
2 BYTES
ETHERNET TYPE
2 BYTES
XWD HEADER
PROTOCOL HEADER
PPP PAYLOAD
XWD MAC
ETHERNET HEADER
XWD MAC PRIMITIVES

FIG. 31

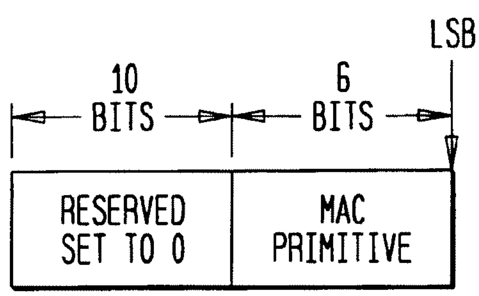

LSB
10 BITS
6 BITS
RESERVED SET TO 0
MAC PRIMITIVE

FIG. 32

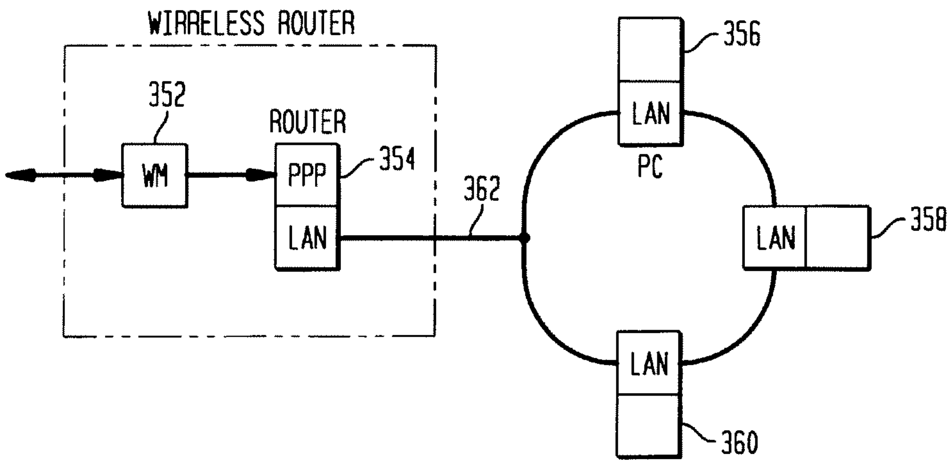
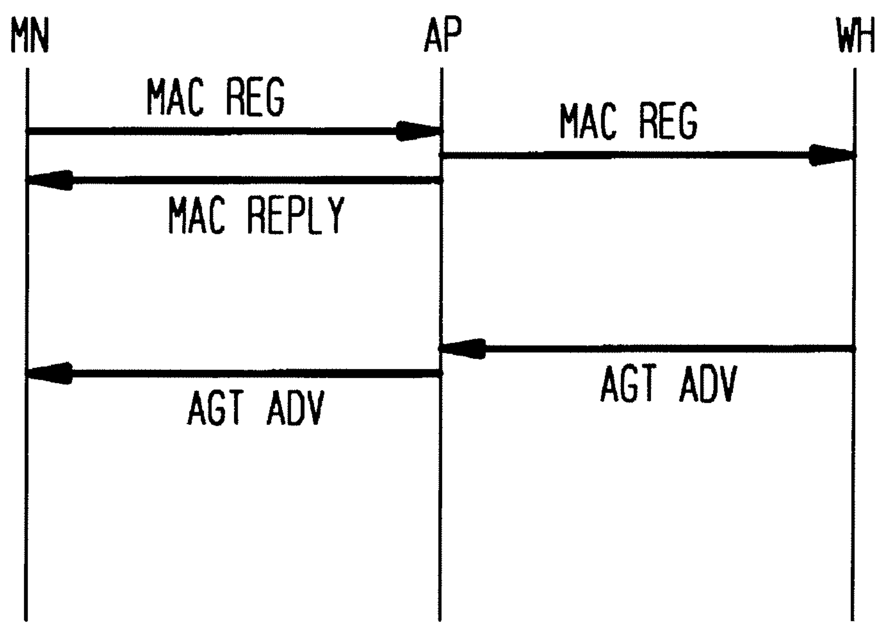
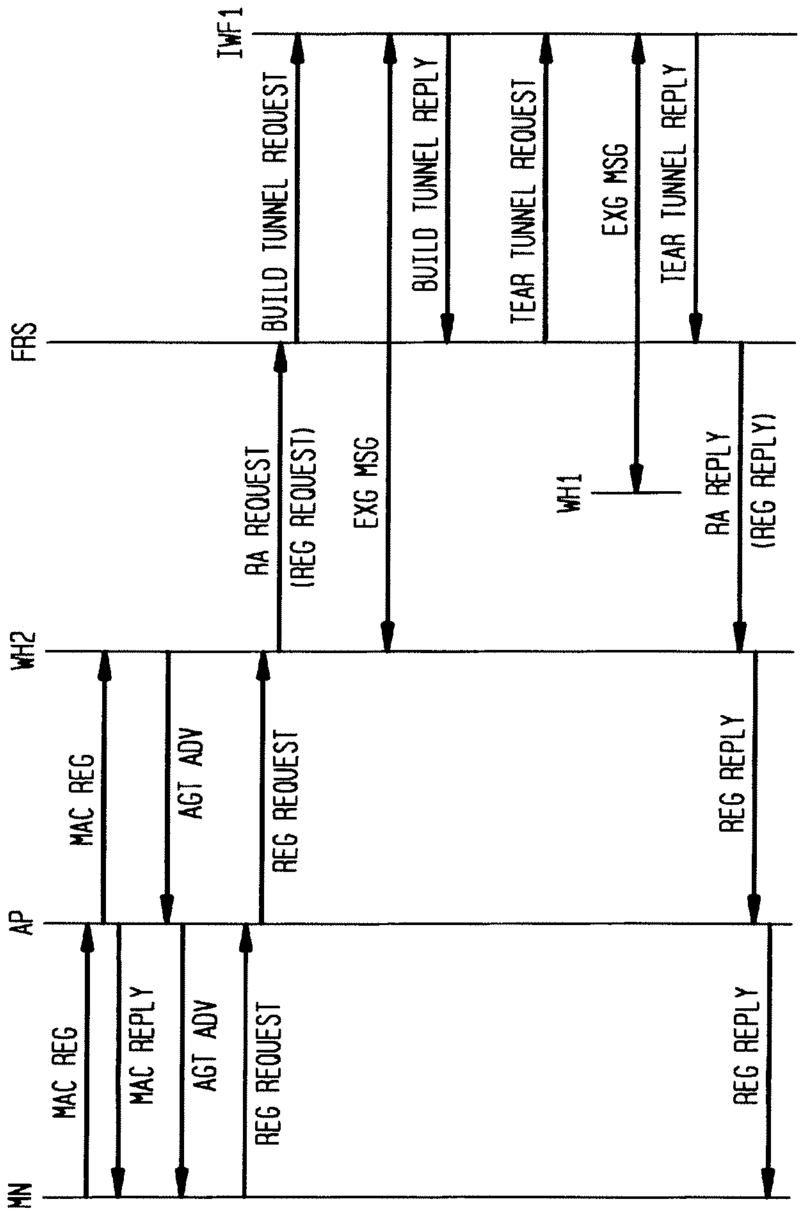

WIRRELESS ROUTER
352
WM
ROUTER
PPP
LAN
354
362
356
LAN
PC
LAN
358
LAN
360

FIG. 33



LOCAL HANDOFF

FIG. 34


MN
AP
WH2
FRS
IWF1
MAC REG
MAC REPLY
AGT ADV
REG REQUEST
REG REPLY
MAC REG
AGT ADV
REG REQUEST
REG REPLY
RA REQUEST
(REG REQUEST)
EXG MSG
WH1
RA REPLY
(REG REPLY)
BUILD TUNNEL REQUEST
BUILD TUNNEL REPLY
TEAR TUNNEL REQUEST
EXG MSG
TEAR TUNNEL REPLY
MICRO MOBILITY

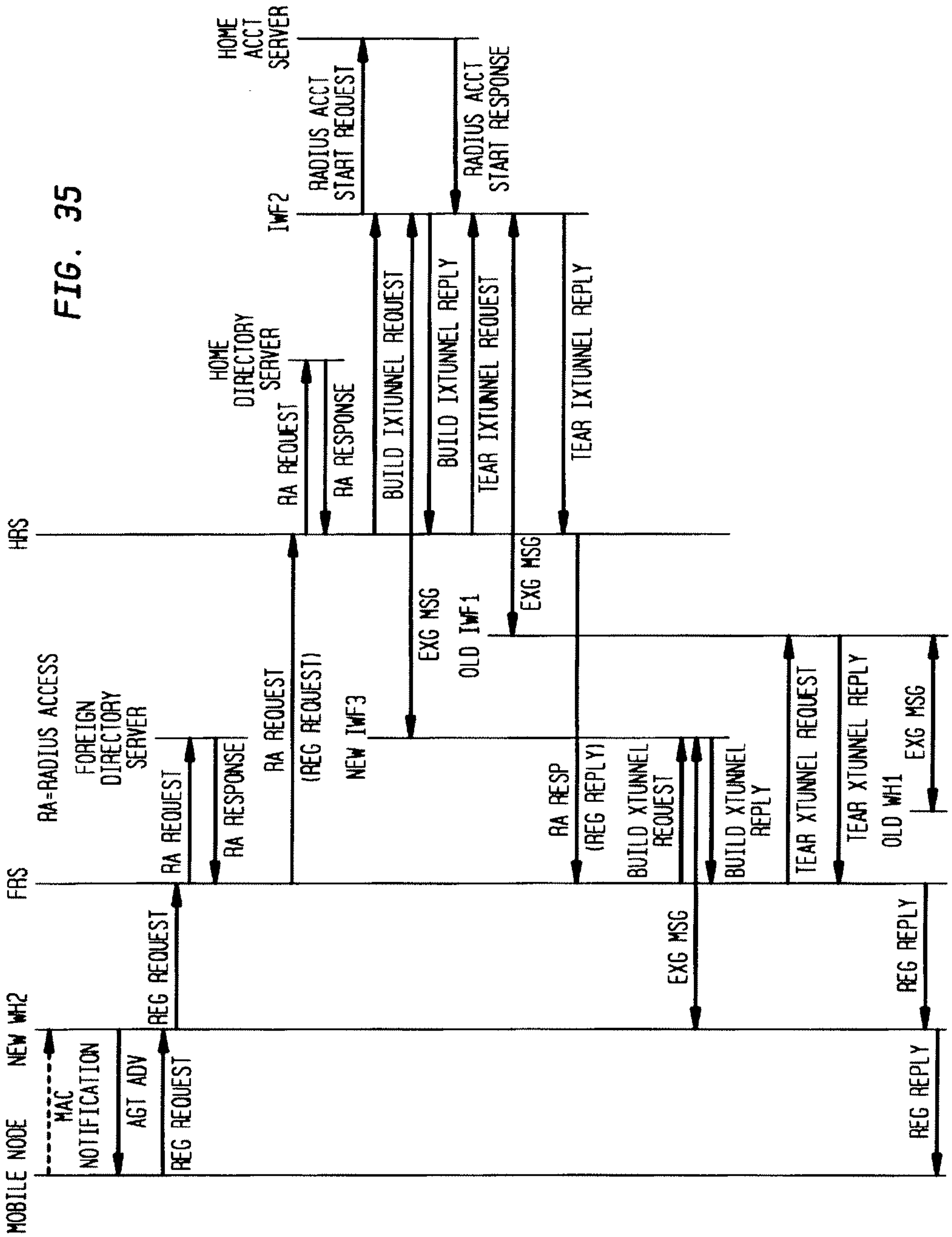

RA=RADIUS ACCESS
MOBILE NODE
NEW WH2
FRS
HRS
FOREIGN DIRECTORY SERVER
HOME DIRECTORY SERVER
IWF2
HOME ACCT SERVER
MAC NOTIFICATION
AGT ADV
REG REQUEST
REG REQUEST
RA REQUEST
RA RESPONSE
RA REQUEST
(REG REQUEST)
RA REQUEST
RA RESPONSE
RADIUS ACCT START REQUEST
RADIUS ACCT START RESPONSE
BUILD IXTUNNEL REQUEST
BUILD IXTUNNEL REPLY
TEAR IXTUNNEL REQUEST
TEAR IXTUNNEL REPLY
EXG MSG
NEW IWF3
EXG MSG
OLD IWF1
RA RESP
(REG REPLY)
BUILD XTUNNEL REQUEST
BUILD XTUNNEL REPLY
EXG MSG
TEAR XTUNNEL REQUEST
TEAR XTUNNEL REPLY
OLD WH1
EXG MSG
REG REPLY
REG REPLY

FIG. 35

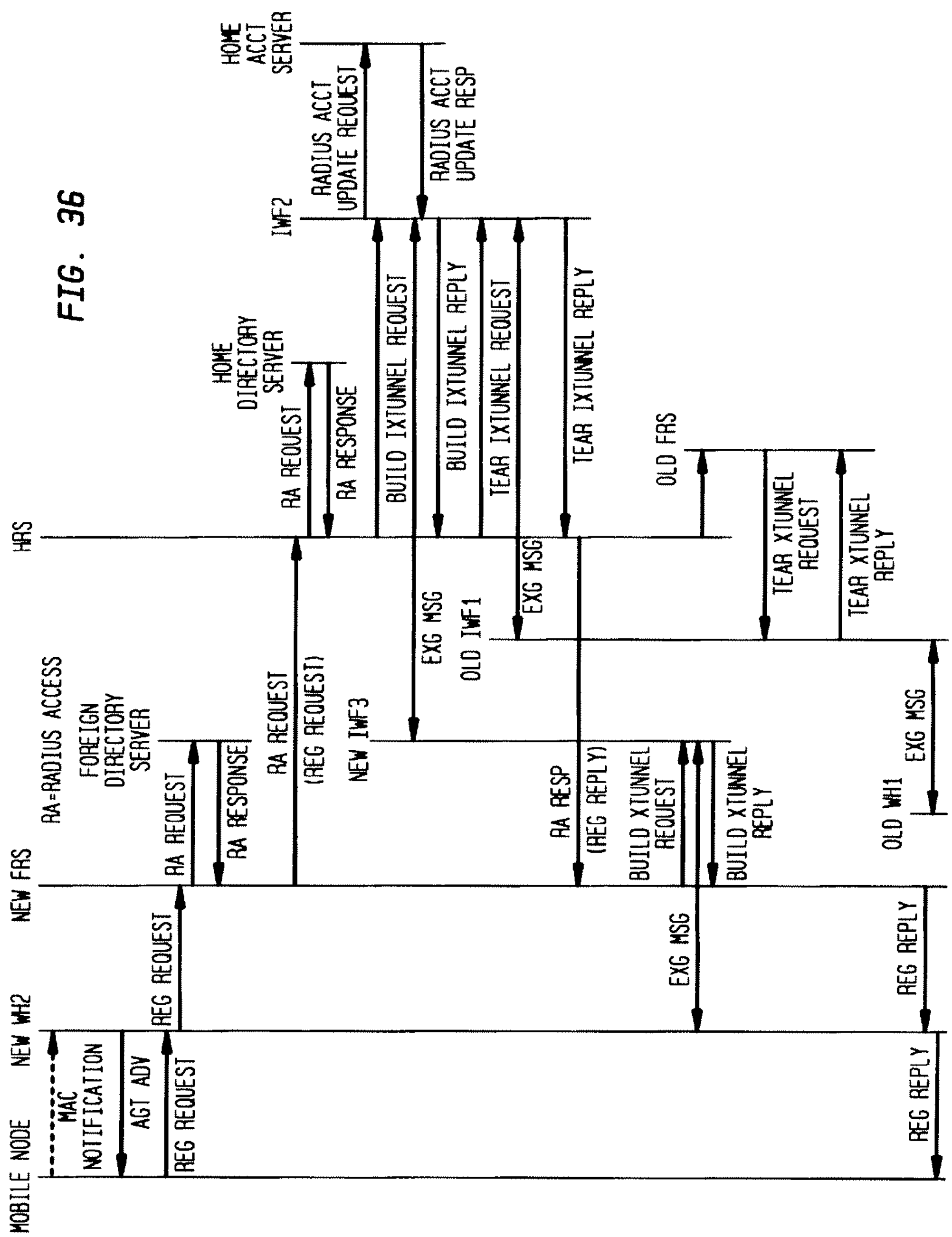

RA=RADIUS ACCESS
MOBILE NODE
NEW WH2
NEW FRS
HRS
FOREIGN DIRECTORY SERVER
NEW IWF3
OLD IWF1
OLD WH1
OLD FRS
HOME DIRECTORY SERVER
IWF2
HOME ACCT SERVER
MAC NOTIFICATION
AGT ADV
REG REQUEST
REG REQUEST
RA REQUEST
RA RESPONSE
RA REQUEST
(REG REQUEST)
RA REQUEST
RA RESPONSE
BUILD IXTUNNEL REQUEST
RADIUS ACCT UPDATE REQUEST
RADIUS ACCT UPDATE RESP
BUILD IXTUNNEL REPLY
EXG MSG
TEAR IXTUNNEL REQUEST
EXG MSG
TEAR IXTUNNEL REPLY
RA RESP
(REG REPLY)
BUILD XTUNNEL REQUEST
EXG MSG
BUILD XTUNNEL REPLY
TEAR XTUNNEL REQUEST
TEAR XTUNNEL REPLY
EXG MSG
REG REPLY
REG REPLY

FIG. 36

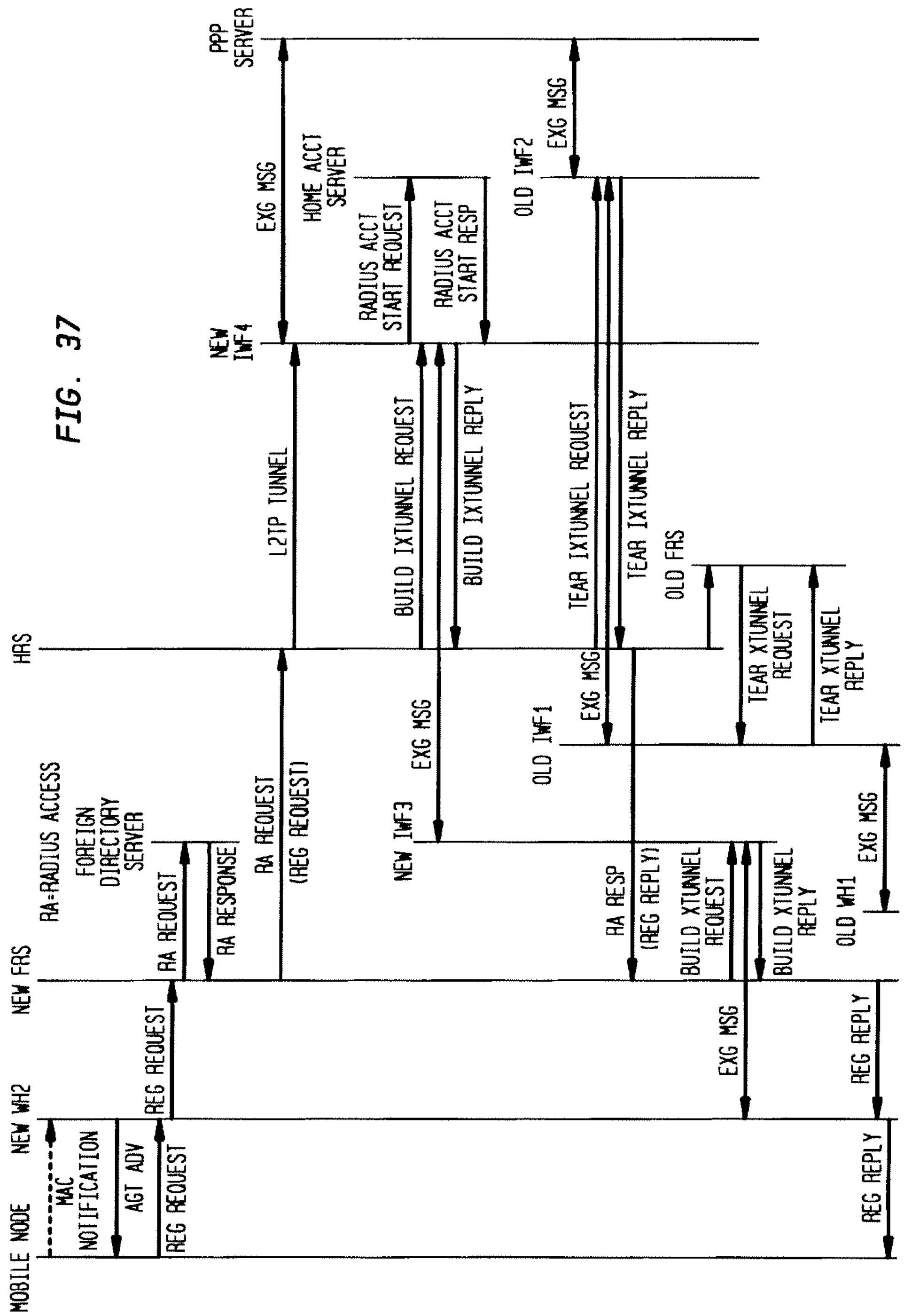

MOBILE NODE
NEW WH2
NEW FRS
HRS
NEW IWF4
PPP SERVER
HOME ACCT SERVER
OLD IWF2
OLD FRS
OLD IWF1
NEW IWF3
OLD WH1
FOREIGN DIRECTORY SERVER
RA=RADIUS ACCESS
MAC NOTIFICATION
AGT ADV
REG REQUEST
REG REQUEST
RA REQUEST
RA RESPONSE
RA REQUEST
(REG REQUEST)
L2TP TUNNEL
EXG MSG
RADIUS ACCT START REQUEST
RADIUS ACCT START RESP
BUILD IXTUNNEL REQUEST
BUILD IXTUNNEL REPLY
EXG MSG
EXG MSG
TEAR IXTUNNEL REQUEST
TEAR IXTUNNEL REPLY
EXG MSG
TEAR XTUNNEL REQUEST
TEAR XTUNNEL REPLY
RA RESP
(REG REPLY)
BUILD XTUNNEL REQUEST
BUILD XTUNNEL REPLY
EXG MSG
EXG MSG
REG REPLY
REG REPLY

FIG. 37

SEQUENCE DELIVERY OF MESSAGES

BACKGROUND OF THE INVENTION

Priority benefit of the Oct. 14, 1997 filing date of provisional application serial No. 60/061,915 is hereby claimed.

FIELD OF THE INVENTION

The present invention relates to a coupled data network, and more particularly to in sequence delivery of messages in the coupled data network.

DESCRIPTION OF RELATED ART

FIG. **1** depicts three business entities, whose equipment, working together typically provide remote internet access to user computers **2** through user modems **4**. User computers **2** and modems **4** constitute end systems.

The first business entity is the telephone company (telco) that owns and operates the dial-up plain old telephone system (POTS) or integrated services data network (ISDN) network. The telco provides the media in the form of public switched telephone network (PSTN) **6** over which bits (or packets) can flow between users and the other two business entities.

The second business entity is the internet service provider (ISP). The ISP deploys and manages one or more points of presence (POPs) **8** in its service area to which end users connect for network service. An ISP typically establishes a POP in each major local calling area in which the ISP expects to subscribe customers. The POP converts message traffic from the PSTN run by the telco into a digital form to be carried over intranet backbone **10** owned by the ISP or leased from an intranet backbone provider like MCI, Inc. An ISP typically leases fractional or full T1 lines or fractional or full T3 lines from the telco for connectivity to the PSTN. The POPs and the ISP's medium data center **14** are connected together over the intranet backbone through router **12A**. The data center houses the ISP's web servers, mail servers, accounting and registration servers, enabling the ISP to provide web content, e-mail and web hosting services to end users. Future value added services may be added by deploying additional types of servers in the data center. The ISP also maintains router **12A** to connect to public internet backbone **20**. In the current model for remote access, end users have service relationships with their telco and their ISP and usually get separate bills from both. End users access the ISP, and through the ISP, public internet **20**, by dialing the nearest POP and running a communication protocol known as the Internet Engineering Task Force (IETF) point-to-point protocol (PPP).

The third business entity is the private corporation which owns and operates its own private intranet **18** through router **12B** for business reasons. Corporate employees may access corporate network **18** (e.g., from home or while on the road) by making POTS/ISDN calls to corporate remote access server **16** and running the IETF PPP protocol. For corporate access, end users only pay for the cost of connecting to corporate remote access server **16**. The ISP is not involved. The private corporation maintains router **12B** to connect an end user to either corporate intranet **18** or public internet **20** or both.

End users pay the telco for the cost of making phone calls and for the cost of a phone line into their home. End users also pay the ISP for accessing the ISP's network and services. The present invention will benefit wireless service providers like Sprint PCS, PrimeCo, etc. and benefit internet service providers like AOL, AT&T Worldnet, etc.

Today, internet service providers offer internet access services, web content services, e-mail services, content hosting services and roaming to end users. Because of low margins and no scope of doing market segmentation based on features and price, ISPs are looking for value added services to improve margins. In the short term, equipment vendors will be able to offer solutions to ISPs to enable them to offer faster access, virtual private networking (which is the ability to use public networks securely as private networks and to connect to intranets), roaming consortiums, push technologies and quality of service. In the longer term, voice over internet and mobility will also be offered. ISPs will use these value added services to escape from the low margin straitjacket. Many of these value added services fall in the category of network services and can be offered only through the network infrastructure equipment. Others fall in the category of application services which require support from the network infrastructure, while others do not require any support from the network infrastructure. Services like faster access, virtual private networking, roaming, mobility, voice, quality of service, quality of service based accounting all need enhanced network infrastructure. The invention described here will be either directly provide these enhanced services or provide hooks so that these services can be added later as future enhancements. Wireless service providers will be able to capture a larger share of the revenue stream. The ISP will be able to offer more services and with better market segmentation.

SUMMARY OF THE INVENTION

The present invention provide end users with remote wireless access to the public internet, private intranets and internet service providers. Wireless access is provided through base stations in a home network and base stations in foreign networks with interchange agreements.

It is an object of the present invention to provide a wireless packet switched data network for end users that divides mobility management into local, micro, macro and global connection handover categories and minimizes handoff updates according to the handover category. It is another object to integrate MAC handoff messages with network handoff messages. It is a further object of the present invention to separately direct registration functions to a registration server and direct routing functions to inter-working function units. It is yet another object to provide an intermediate XTunnel channel between a wireless hub (also called access hub AH) and an inter-working function unit (IWF unit) in a foreign network. It is yet another object to provide an IXTunnel channel between an inter-working function unit in a foreign network and an inter-working function unit in a home network. It is yet another object to enhance the layer two tunneling protocol (L2TP) to support a mobile end system. It is yet another object to perform network layer registration before the start of a PPP communication session.

According to one embodiment of the invention, a coupled data network which ensures in sequence delivery of messages is disclosed. The copuled data network includes a foreign network and a home network. The foreign network includes a foreign mobile switching center and a base station, the base station including an access hub with a serving inter-working function. The home network includes a home mobile switching center, the home mobile switching center including a home inter-working function. A roaming end system is a subscriber to the home network and operates within the foreign network, a message being transportable between the roaming end system and the home inter-

working function through the serving inter-working function using a protocol that ensures in sequence delivery of data packets.

According to another embodiment of the invention, a data network with a home network is disclosed. The home network includes a home mobile switching center, the home mobile switching center including a home inter-working function. An end system is a subscriber to the home network and operates within the foreign network. A message is transportable between the end system and the home inter-working function through the serving inter-working function using a protocol that ensures in sequence delivery of data packets.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be described in detail in the following description of preferred embodiments with reference to the following figures wherein:

FIG. **1** is a configuration diagram of a known remote access architecture through a public switched telephone network;

FIG. **2** is a configuration diagram of a remote access architecture through a wireless packet switched data network according to the present invention;

FIG. **3** is a configuration diagram of selected parts of the architecture of the network of FIG. **2** showing a roaming scenario;

FIG. **4** is a configuration diagram of a base station with local access points;

FIG. **5** is a configuration diagram of a base station with remote access points;

FIG. **6** is a configuration diagram of a base station with remote access points, some of which are connected using a wireless trunk connection;

FIG. **7** is a diagram of a protocol stack for a local access point;

FIG. **8** is a diagram of a protocol stack for a remote access point with a wireless trunk;

FIG. **9** is a diagram of a protocol stack for a relay function in the base station for supporting remote access points with wireless trunks;

FIG. **10** is a diagram of protocol stacks for implementing the relay function depicted in FIG. **9**;

FIG. **11** is a diagram of protocol stacks for a relay function in the base station for supporting local access points;

FIG. **12** is a configuration diagram of selected parts of the architecture of the network of FIG. **2** showing a first end system registering in the home network from the home network and a second system registering in the home network from a foreign network using a home inter-working function for an anchor;

FIG. **13** is a configuration diagram of selected parts of the architecture of the network of FIG. **2** showing a first end system registering in the home network from the home network and a second system registering in the home network from a foreign network using a serving inter-working function for an anchor;

FIG. **14** is a ladder diagram of the request and response messages to register in a home network from a foreign network and to establish, authenticate and configure a data link;

FIG. **15** is a configuration diagram of selected parts of the architecture of the network of FIG. **2** showing registration requests and responses for registering a mobile in a home network from the home network;

FIG. **16** is a configuration diagram of selected parts of the architecture of the network of FIG. **2** showing registration requests and responses for registering a mobile in a home network from a foreign network;

FIG. **17** is a configuration diagram of protocol stacks showing communications between an end system in a home network and an inter-working function in the home network where the cell site has local access points;

FIG. **18** is a configuration diagram of protocol stacks showing communications between an end system in a home network and an inter-working function in the home network where the cell site has remote access points coupled to a wireless hub through a wireless trunk;

FIG. **19** is a configuration diagram of protocol stacks showing communications between a base station coupled to a roaming end system and a home inter-working function;

FIG. **20** is a configuration diagram of protocol stacks showing communications between an end system in a home network through an inter-working function in the home network to an internet service provider;

FIG. **21** is a configuration diagram of protocol stacks showing communications between an end system in a foreign network and a home registration server in a home network during the registration phase;

FIG. **22** is a processing flow diagram showing the processing of accounting data through to the customer billing system;

FIGS. **23** and **24** are ladder diagrams depicting the registration process for an end system in a home network and in a foreign network, respectively;

FIGS. **25** and **26** are protocol stack diagrams depicting an end system connection in a home network where a PPP protocol terminates in an inter-working function of the home network and where the PPP protocol terminates in an ISP or intranet, respectively;

FIGS. **27** and **28** are protocol stack diagrams depicting an end system connection in a foreign network where a PPP protocol terminates in an inter-working function of the foreign network and where the PPP protocol terminates in an ISP or intranet, respectively;

FIG. **29** illustrates end systems connected via ethernet to a wireless modem where PPP protocol is encapsulated in an ethernet frame;

FIG. **30** illustrates an ethernet frame format;

FIG. **31** illustrates XWD Header fields;

FIG. **32** illustrates end systems connected via a local area network to a wireless router where PPP protocol terminates at the wireless router;

FIGS. **33**, **34** and **35** are ladder diagrams depicting a local handoff scenario, a micro handoff scenario and a macro handoff scenario, respectively;

FIG. **36** is a ladder diagram depicting a global handoff scenario where the foreign registration server changes and where home inter-working function does not change; and

FIG. **37** is a ladder diagram depicting a global handoff scenario where both the foreign registration server and the home inter-working function change.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides computer users with remote access to the internet and to private intranets using virtual private network services over a high speed, packet switched, wireless data link. These users are able to access

the public internet, private intranets and their internet service providers over a wireless link. The network supports roaming, that is, the ability to access the internet and private intranets using virtual private network services from anywhere that the services offered by the present system are available. The network also supports handoffs, that is, the ability to change the point of attachment of the user to the network without disturbing the PPP link between the PPP client and the PPP server. The network targets users running horizontal internet and intranet applications. These applications include electronic mail, file transfer, browser based WWW access and other business applications built around the internet. Because the network will be based on the IETF standards, it is possible to run streaming media protocols like RTP and conferencing protocols like H.323 over it.

Other internet remote access technologies that are already deployed or are in various stages of deployment include: wire line dial-up access based on POTS and ISDN, XDSL access, wireless circuit switched access based on GSM/CDMA/TDMA, wireless packet switched access based on GSM/CDMA/TDMA, cable modems, and satellite based systems. However, the present system offers a low cost of deployment, ease of maintenance, a broad feature set, scaleability, an ability to degrade gracefully under heavy load conditions and support for enhanced network services like virtual private networking, roaming, mobility and quality of service to the relative benefit of users and service providers.

For wireless service providers who own personal communications system (PCS) spectrum, the present system will enable them to offer wireless packet switched data access services that can compete with services provided by the traditional wire line telcos who own and operate the PSTN. Wireless service providers may also decide to become internet service providers themselves, in which case, they will own and operate the whole network and provide end to end services to users.

For internet service providers the present system will allow them to by-pass the telcos (provided they purchase or lease the spectrum) and offer direct end to end services to users, perhaps saving access charges to the telcos, which may increase in the future as the internet grows to become even bigger than it is now.

The present systems flexible so that it can benefit wireless service providers who are not internet service providers and who just provide ISP, internet or private intranet access to end users. The system can also benefit service providers who provide wireless access and internet services to end users. The system can also benefit service providers who provide wireless access and internet services but also allow the wireless portion of the network to be used for access to other ISPs or to private intranets.

In FIG. **2**, end systems **32** (e.g., based on, for example, Win 95 personal computer) connect to wireless network **30** using external or internal modems. These modems allow end systems to send and receive medium access control (MAC) frames over air link **34**. External modems attach to the PC via a wired or wireless link. External modems are fixed, and, for example, co-located with roof top mounted directional antennae. External modems may be connected to the user's PC using any one of following means: 802.3, universal serial bus, parallel port, infra-red, or even an ISM radio link. Internal modems are preferably PCMCIA cards for laptops and are plugged into the laptop's backplane. Using a small omni-directional antenna, they send and receive MAC frames over the air link. End systems can also be laptops

with a directional antenna, a fixed wireless station in a home with a directional antenna connected via AC lines, and other alternatives.

Wide-area wireless coverage is provided by base stations **36**. The base station **36** can employ a 5-channel reuse communication scheme as described in U.S. patent application Ser. No. 08/998,505, filed on Dec. 26, 1997. The range of coverage provided by base stations **36** depends on factors like link budget, capacity and coverage. Base stations are typically installed in cell sites by PCS (personal communication services) wireless service providers. Base stations multiplex end system traffic from their coverage area to the system's mobile switching center (MSC) **40** over wire line or microwave backhaul network **38**.

The system is independent of the MAC and PHY (physical) layer of the air link and the type of modem. The architecture is also independent of the physical layer and topology of backhaul network **38**. The only requirements for the backhaul network are that it must be capable of routing internet protocol (IP) packets between base stations and the MSC with adequate performance. At Mobile Switching Center **40** (MSC **40**), packet data inter-working function (IWF) **52** terminates the wireless protocols for this network. IP router **42** connects MSC **40** to public internet **44**, private intranets **46** or to internet service providers **46**. Accounting and directory servers **48** in MSC **40** store accounting data and directory information. Element management server **50** manages the equipment which includes the base stations, the IWFs and accounting/directory servers.

The accounting server will collect accounting data on behalf of users and send the data to the service provider's billing system. The interface supported by the accounting server will send accounting information in American Management Association (AMA) billing record format, or any other suitable billing format, over a TCP/IP (transport control protocol/internet protocol) transport to the billing system (which is not shown in the figure).

The network infrastructure provides PPP (point-to-point protocol) service to end systems. The network provides (1) fixed wireless access with roaming (log-in anywhere that the wireless coverage is available) to end systems and (2) low speed mobility and hand-offs. When an end system logs on to a network, in it may request either fixed service (i.e., stationary and not requiring handoff services) or mobile service (i.e., needing handoff services). An end system that does not specify fixed or mobile is regarded as specifying mobile service. The actual registration of the end system is the result of a negotiation with a home registration server based on requested level of service, the level of services subscribed to by the user of the end system and the facilities available in the network.

If the end system negotiates a fixed service registration (i.e., not requiring handoff services) and the end system is located in the home network, an IWF (inter-working function) is implemented in the base station to relay traffic between the end user and a communications server such as a PPP server (i.e., the point with which to be connected, for example, an ISP PPP server or a corporate intranet PPP server or a PPP server operated by the wireless service provider to provide customers with direct access to the public internet). It is anticipated that perhaps 80% of the message traffic will be of this category, and thus, this architecture distributes IWF processing into the base stations and avoids message traffic congestion in a central mobile switching center.

If the end system requests mobile service (from a home network or a foreign network) or if the end system request

roaming service (i.e., service from the home network through a foreign network), two IWFs are established: a serving IWF typically established in the base station of the network to which the end system is attached (be it the home network or a foreign network) and a home IWF typically established in mobile switching center MSC of the home network. Since this situation is anticipated to involve only about 20% of the message traffic, the message traffic congestion around the mobile switching center is minimized. The serving IWF and the wireless hub may be co-located in the same nest of computers or may even be programmed in the same computer so that a tunnel using an XTunnel protocol need not be established between the wireless hub and the serving IWF.

However, based on available facilities and the type and quality of service requested, a serving IWF in a foreign network may alternatively be chosen from facilities in the foreign MSC. Generally, the home IWF becomes an anchor point that is not changed during the communications session, while the serving IWF may change if the end system moves sufficiently.

The base station includes an access hub and at least one access point (be it remote or collocated with the access hub). Typically, the access hub serves multiple access points. While the end system may be attached to an access point by a wire or cable according to the teachings of this invention, in a preferred embodiment the end system is attached to the access point by a wireless "air link", in which case the access hub is conveniently referred to as a wireless hub. While the access hub is referred to as a "wireless hub" throughout the description herein, it will be appreciated that an end system coupled through an access point to an access hub by wire or cable is an equivalent implementation and is contemplated by the term "access hub".

In the invention, an end system includes an end user registration agent (e.g., software running on a computer of the end system, its modem or both) that communicates with an access point, and through the access point to a wireless hub. The wireless hub includes a proxy registration agent (e.g., software running on a processor in the wireless hub) acting as a proxy for the end user registration agent. Similar concepts used in, for example, the IETF proposed Mobile IP standard are commonly referred to as a foreign agent (FA). For this reason, the proxy registration agent of the present system will be referred to as a foreign agent, and aspects of the foreign agent of the present system that differ from the foreign agent of Mobile IP are as described throughout this description.

Using the proxy registration agent (i.e., foreign agent FA) in a base station, the user registration agent of an end system is able to discover a point of attachment to the network and register with a registration server in the MSC (mobile switching center) of the home network. The home registration server determines the availability of each of the plural inter-working function modules (IWFs) in the network (actually software modules that run on processors in both the MSC and the wireless hubs) and assigns IWF(s) to the registered end system. For each registered end system, a tunnel (using the XTunnel protocol) is created between the wireless hub in the base station and an inter-working function (IWF) in the mobile switching center (MSC), this tunnel transporting PPP frames between the end system and the IWF.

As used herein, the XTunnel protocol is a protocol that provides in-sequence transport of PPP data frames with flow control. This protocol may run over standard IP networks or over point-to-point networks or over switched networks like ATM data networks or frame relay data networks. Such networks may be based on T1 or T3 links or based on radio links, whether land based or space based. The XTunnel protocol may be built by adapting algorithms from L2TP (level 2 transport protocol). In networks based on links where lost data packets may be encountered, a re-transmission feature may be a desirable option.

The end system's PPP peer (i.e., a communications server) may reside in the IWF or in a corporate intranet or ISP's network. When the PPP peer resides in the IWF, an end system is provided with direct internet access. When the PPP peer resides in an intranet or ISP, an end system is provided with intranet access or access to an ISP. In order to support intranet or ISP access, the IWF uses the layer two tunneling protocol (L2TP) to connect to the intranet or ISP's PPP server. From the point of view of the intranet or ISP's PPP server, the IWF looks like a network access server (NAS). PPP traffic between the end system and the IWF is relayed by the foreign agent in the base station.

In the reverse (up link) direction, PPP frames traveling from the end system to the IWF are sent over the MAC and air link to the base station. The base station relays these frames to the IWF in the MSC using the XTunnel protocol. The IWF delivers them to a PPP server for processing. For internet access, the PPP server may be in the same machine as the IWF. For ISP or intranet access, the PPP server is in a private network and the IWF uses the layer two tunneling protocol (L2TP) to connect to it.

In the forward (down link) direction, PPP frames from the PPP server are relayed by the IWF to the base station using the XTunnel protocol. The base station de-tunnels down link frames and relays them over the air link to the end system, where they are processed by the end system's PPP layer.

To support mobility, support for hand-offs are included. The MAC layer assists the mobility management software in the base station and the end system to perform hand-offs efficiently. Hand-offs are handled transparently from the peer PPP entities and the L2TP tunnel. If an end system moves from one base station to another, a new XTunnel is created between the new base station and the original IWF. The old XTunnel from the old base station will be deleted. PPP frames will transparently traverse the new path.

The network supports roaming (i.e., when the end user connects to its home wireless service provider through a foreign wireless service provider). Using this feature, end systems are able to roam away from the home network to a foreign network and still get service, provided of course that the foreign wireless service provider and the end system's home wireless service provider have a service agreement.

In FIG. **3**, roaming end system **60** has traveled to a location at which foreign wireless service provider **62** provides coverage. However, roaming end system **60** has a subscriber relationship with home wireless service provider **70**. In the present invention, home wireless service provider **70** has a contractual relationship with foreign wireless service provider **62** to provide access services. Therefore, roaming end system **60** connects to base station **64** of foreign wireless service provider **62** over the air link. Then, data is relayed from roaming end system **60** through base station **64**, through serving IWF **66** of foreign wireless service provider **62**, to home IWF **72** of home wireless service provider **70**, or possibly through home IWF **72** of home wireless service provider **70** to internet service provider **74**.

An inter-service provider interface, called the I-interface, is used for communications across wireless service provider

(WSP) boundaries to support roaming. This interface is used for authenticating, registering and for transporting the end system's PPP frames between the foreign WSP and the home WSP.

PPP frames in the up link and the down link directions travel through the end system's home wireless service provider (WSP). Alternatively, PPP frames directly transit from the foreign WSP to the destination network. The base station in the foreign WSP is the end system's point of attachment in the foreign network. This base station sends (and receives) PPP frames to (and from) a serving IWF in the foreign WSP's mobile switching center. The serving IWF connects over the I-interface to the home IWF using a layer two tunnel to transport the end system's PPP frames in both directions. The serving IWF in the foreign WSP collects accounting data for auditing. The home IWF in the home WSP collects accounting data for billing.

The serving IWF in the foreign WSP may be combined with the base station in the same system, thus eliminating the need for the X-Tunnel.

During the registration phase, a registration server in the foreign WSP determines the identity of the roaming end system's home network. Using this information, the foreign registration server communicates with the home registration server to authenticate and register the end system. These registration messages flow over the I-interface. Once the end system has been authenticated and registered, a layer two tunnel is created between the base station and the serving IWF using the XTUNNEL protocol and another layer two tunnel is created between the serving IWF and the home IWP over the I-interface. The home IWF connects to the end system's PPP peer as before, using L2TP (level **2** tunnel protocol). During hand-offs, the location of the home IWF and the L2TP tunnel remains fixed. As the end system moves from one base station to another base station, a new tunnel is created between the new base station and the serving IWF and the old tunnel between the old base station and the serving IWF is deleted. If the end system moves far enough, so that a new serving IWF is needed, a new tunnel will be created between the new serving IWF and the home IWF. The old tunnel between the old serving and the home will be deleted.

To support roaming, the I-interface supports authentication, registration and data transport services across wireless service provider boundaries. Authentication and registration services are supported using the IETF Radius protocol. Data transport services to transfer PPP frames over a layer two tunnel are supported using the I-XTunnel protocol. This protocol is based on the IETF L2TP protocol.

As used in this description, the term home IWF refers to the IWF in the end system's home network. The term serving IWF refers to the IWF in the foreign network which is temporarily providing service to the end system. Similarly, the term home registration server refers to the registration server in the end system's home network and the term foreign registration server refers to the registration server in the foreign network through which the end system registers while it is roaming.

The network supports both fixed and dynamic IP address assignment for end systems. There are two types of IP addresses that need to be considered. The first is the identity of the end system in its home network. This may be a structured user name in the format user@domain. This is different from the home IP address used in mobile IP. The second address is the IP address assigned to the end system via the PPP IPCP address negotiation process. The domain sub-field of the home address is used to identify the user's home domain and is a fully qualified domain name. The user sub-field of the home address is used to identify the user in the home domain. The User-Name is stored on the end system and in the subscriber data-base at the MSC and is assigned to the user when he or she subscribes to the service. The domain sub-field of the User-Name is used during roaming to identify roaming relationships and the home registration server for purposes of registration and authe structured user name another unique identifier may be used to identify the user's home network and the user's identity in the home network. This identifier is sent in the registration request by the end system

The PPP IPCP is used to negotiate the IP address for the end system. Using IP configuration protocol IPCP, the end system is able to negotiate a fixed or dynamic IP address.

Although the use of the structured user-name field and the non-use of an IP address as the home address is a feature that characterizes the present system over a known mobile IP, the network may be enhanced to also support end systems that have no user-name and only a non-null home address, if mobile IP and its use in conjunction with PPP end systems becomes popular. The PPP server may be configured by the service provider to assign IP addresses during the IPCP address assignment phase that are the same as the end system's home IP address. In this case, the home address and the IPCP assigned IP address will be identical.

In FIG. **4**, base station **64** and air links from end systems form wireless sub-network **80** that includes the air links for end user access, at least one base station (e.g., station **64**) and at least one backhaul network (e.g., **38** of FIG. **2**) from the base station to MSC **40** (FIG.**2**). The wireless sub-network architecture of, for example, a 3-sectored base station includes the following logical functions.

1. Access point function. Access points **82** perform MAC layer bridging and MAC layer association and dissociation procedures. An access point includes a processor (preferably in the form of custom application specific integrated circuit ASIC), a link to a wireless hub (preferably in the form of an Ethernet link on a card or built into the ASIC), a link to an antenna (preferably in the form of a card with a data modulator/demodulator and a transmitter/receiver), and the antenna to which the end system is coupled. The processor runs software to perform a data bridging function and various other functions in support of registration and mobility handovers as further described herein. See discussion with respect to FIGS. **7**, **8** and **11**.

   Access points (APs) take MAC layer frames from the air link and relay them to a wireless hub and vice versa. The MAC layer association and disassociation procedures are used by APs to maintain a list of end system MAC addresses in their MAC address filter table. An AP will only perform MAC layer bridging on behalf of end systems whose MAC addresses are present in the table. An access point and its associated wireless hub are typically co-located. In its simplest form, an access point is just a port into a wireless hub. When the APs and the wireless hub are co-located in the same cell site, they may be connected together via a IEEE 802.3 link. Sometimes, access points are located remotely from the wireless hub and connected via a long distance link like a wired T1 trunk or even a wireless trunk. For multisector cells, multiple access points (i.e., one per sector) are used.

2. Wireless hub function. Wireless hub **84** performs the foreign agent (FA) procedures, backhaul load balancing (e.g., over multiple T1's), backhaul network interfacing, and the xtunnel procedures. When support for quality of service (QOS) is present, the wireless hub implements the support for QOS by running the xtunnel protocol over backhauls with different QOS attributes. In a multi-sector cell site, a single wireless hub function is typically shared by multiple access points.

A wireless hub includes a processor, a link to one or more access points (preferably in the form of an Ethernet link on a card or built into an ASIC), and a link to a backhaul line. The backhaul line is typically a T1 or T3 communications line that terminates in the mobile switching center of the wireless service provider. The link to the backhaul line formats data into a preferred format, for example, an Ethernet format, a frame relay format or an ATM format. The wireless hub processor runs software to support data bridging and various other functions as described herein. See discussion with respect to FIGS. **9**, **10** and **11**.

The base station design supports the following types of cell architectures.

1. Local AP architecture. In a local AP architecture, access points have a large (>=2 km, typically) range. They are co-located in the cell site with the wireless hub (FIG. **4**). Access points may be connected to the wireless hub using an IEEE 802.3 network or may be directly plugged into the wireless hub's backplane or connected to the wireless hub using some other mechanism (e.g. universal serial bus, printer port, infra-red, etc.). It will be assumed that the first alternative is used for the rest of this discussion. The cell site may be omni or sectored by adding multiple access points and sectored antennas to a wireless hub.
2. Remote AP architecture. In a remote AP architecture, access points usually have a very small range, typically around 1 km radius. They are located remotely (either indoors or outdoors) from the wireless hub. A T1 or a wireless trunk preferably links remote access points to the cell site where the wireless hub is located. From the cell site, a wire line backhaul or a microwave link is typically used to connect to the IWF in the MSC. If wireless trunking between the remote AP and the wireless hub is used, omni or sectored wireless radios for trunking are utilized. The devices for trunking to remote access points are preferably co-located with the wireless hub and may be connected to it using an IEEE 802.3 network or may be directly plugged into the wireless hub's backplane. These devices will be referred to by the term trunk AP.
3. Mixed AP architecture. In a mixed architecture, the wireless sub-network will have to support remote and local access points. Remote access points may be added for hole filling and other capacity reasons. As described earlier, T1 or wireless trunks may be used to connect the remote AP to the wireless hub.

FIG. **5** shows a cell with three sectors using local APs only. The access points and the wireless hub are co-located in the base station and are connected to each other with 802.3 links.

FIG. **6** shows an architecture with remote access points **82** connected to wireless hub **84** using wireless trunks **86**. Each trunk access point in the base station provides a point to multi-point wireless radio link to the remote micro access points (R-AP in figure). The remote access points provide air link service to end systems. The wireless hub and the trunk access points are co-located in the base station and connected together via 802.3 links. This figure also shows remote access points **82R** connected to the wireless hub via point to point T1 links. In this scenario, no trunk APs are required.

To support all of the above cell architectures and the different types of access points that each cell might use, the network architecture follows the following rules:

1. Access points function as MAC layer bridges. Remote access points perform MAC bridging between the air link to the end systems and the wireless or T1 trunk to the cell site. Local access points perform MAC bridging between the air link to the end systems and the wireless hub.
2. Trunk access points also function as MAC layer bridges. They perform MAC bridging between the trunk (which goes to the access points) and the wireless hub.
3. The wireless hub is connected to all co-located MAC bridges (i.e. local access points or trunk access points) using a 802.3 link initially.

Additionally, where local access points or remote access points with T1 trunks are used, the following rules are followed.

1. Local access points are co-located with the wireless hub and connected to it using point to point 802.3 links or a shared 802.3 network. Remote access points are connected to the wireless hub using point to point T1 trunks.
2. Sectorization is supported by adding access points with sectored antennas to the cell site.
3. For each access point connected to the wireless hub, there is a foreign agent executing in the wireless hub which participates in end system registration. MAC layer association procedures are used to keep the MAC address filter tables of the access points up to date and to perform MAC layer bridging efficiently. The wireless hub participates in MAC association functions so that only valid MAC addresses are added to the MAC address filter tables of the access points.
4. The foreign agent in the wireless hub relays frames from the access points to the MSC IWF and vice versa using the xtunnel protocol.

The MAC address filter table is used to filter out those unicast MAC data frames whose MAC addresses are not present in the table. The APs always forward MAC broadcast frames and MAC frames associated with end system registration functions regardless of the contents of the MAC address filter table.

5. Local access points use ARP to resolve MAC addresses for routing IP traffic to the wireless hub. Conversely, the wireless hub also uses ARP to route IP packets to access points. UDP/IP is used for network management of access points.
6. Remote access points connected via T1 do not use ARP since the link will be a point to point link.
7. Support for hand-offs is done with assistance from the MAC layer.

In a cell architecture using wireless trunks and trunk APs, the following rules are followed.

1. Trunk access points are co-located with the wireless hub and connected to it using point to point 802.3 links or other suitable means.
2. Wireless trunk sectorization is supported by adding trunk access points with sectored antennas to the cell site.

3. Hand-offs across backhaul sectors are done using the foreign agent in the wireless hub. For each backhaul sector, there is a foreign agent executing in the wireless hub.
4. The trunk APs do not need to participate in MAC layer end system association and hand off procedures. Their MAC address filter tables will be dynamatically programmed by the wireless hub as end systems register with the network. The MAC address filter table is used to filter out unicast MAC frames. Broadcast MAC frames or MAC frames containing registration packets are allowed to always pass through.
5. Trunk APs use ARP to resolve MAC addresses for routing IP traffic to the wireless hub. Conversely, the wireless hub use ARP to route IP packets to trunk APs. UDP/IP is used for network management of trunk APs.
6. In a single wireless trunk sector, MAC association and hand-offs from one access point to another is done using the MAC layer with the assistance of the foreign agent in the wireless hub. Using these MAC layer procedures, end systems associate with access points. As end systems move from one access point to another access point, the access points will use a MAC hand off protocol to update their MAC address filter tables. The wireless hub at the cell site provides assistance to access points to perform this function. This assistance includes relaying MAC layer hand off messages (since access points will not be able to communicate directly over the MAC layer with each other) and authenticating the end system for MAC layer registration and hand off and for updating the MAC address filter tables of the access points.
7. The foreign agent for a wireless trunk sector is responsible for relaying frames from its trunk AP to the MSC and vice versa using the xtunnel protocol. Thus, the foreign agent for a trunk AP does not care about the location of the end system with respect to access points within that wireless trunk sector. In the down link direction, it just forwards frames from the tunnel to the appropriate trunk AP which uses MAC layer bridging to send the frames to all the remote access points attached in that backhaul sector. The access points consult their MAC address filter tables and either forward the MAC frames over the access network or drop the MAC frames. As described above, the MAC address filter tables are kept up to date using MAC layer association and hand off procedures. In the up link direction, MAC frames are forwarded by the access points to the backhaul bridge which forwards them to the foreign agent in the wireless hub using the 802.3 link.
8. ARP is not be used for sending or receiving IP packets to the remote access points. The access points determines the MAC address of the wireless hub using BOOTP procedures. Conversely, the wireless hub is configured with the MAC address of remote access points. UDP/IP is used for network management of access points and for end system association and hand off messages.

IEEE Standard 802.3 links in the cell site may be replaced by other speed links.

FIG. 7 shows the protocol stack for a local access point. At the base of the stack is physical layer PHY. Physical layer PHY carries data to and from an end system over the air using radio waves as an example. When received from an end system, the AP receives data from the physical layer and unpacks it from the MAC frames (the MAC layer). The end system data frames are then repacked into an Ethernet physical layer format (IEEE 802.3 format) where it is send via the Ethernet link to the wireless hub. When the AP's processor receives data from the wireless hub via its Ethernet link (i.e., the physical layer), the data to be transmitted to an end system, the AP packs the data in a medium access control (MAC) format, and sends the MAC layer data to its modulator to be transmitted to the end system using the PHY layer.

In FIG. 8, the MAC and PHY layers to/from the end system of FIG. 7 are replaced by a MAC and PHY for the trunk to the cell site for a remote access point. Specifically, for a T1 trunk, the high level data link control protocol (HDLC protocol) is preferably used over the T1.

FIG. 9 depicts the protocol stack for the wireless hub that bridges the backhaul line and the trunk to the remote access point. The trunk to the remote APs are only required to support remote access points (as distinct from Ethernet coupled access points). The MAC and PHY layers for the wireless trunk to the remote APs provide a point to multipoint link so that one trunk may be used to communicate with many remote APs in the same sector.

The wireless hub bridges the trunk to the remote APs and the backhaul line (e.g., T1 or T3) to the network's mobile switching center (MSC). The protocol stack in the wireless hub implements MAC and PHY layers to the MSC on top of which is implemented an IP (Internet Protocol) layer on top of which is implemented a UDP layer (Universal Datagram Protocal, in combination referred to as UDP/IP) for network management on top of which is implemented an XTunnel protocol. The XTunnel protocol is a new format that includes aspects of mobility (e.g. as in mobile IP) and aspects of the Level 2 Tunnel Protocol (L2TP). The XTunnel protocol is used to communicate from the wireless hub to the MSC and between inter-working functions (IWFs) in different networks or the same network.

In FIG. 10, the protocol stack for the relay function in the base station for supporting remote access points is shown. The relay function includes an interface to the backhaul line (depicted as the wireless hub) and an interface to the remote AP (depicted as a trunk AP). From the point of view of the wireless hub, the trunk AP (depicted in FIGS. 7 and 10) actually behaves like the AP depicted in FIG. 7. Preferably, the base station protocol stacks are split up into a wireless hub and a trunk AP with an Ethernet in between. In an N-sector wireless trunk, there are N wireless trunk APs in the cell site and one wireless hub.

In FIG. 11, the base station protocol stack for a cell architecture using a local AP is shown. The relay function includes an interface to the backhaul line (depicted as the wireless hub) and an air link interface to the end system (depicted as an AP). From the point of view of the wireless hub, the AP (depicted in FIGS. 8 and 11) actually behaves like the trunk AP depicted in FIG. 8. Preferably, the base station protocol stacks are split up into a wireless hub and a trunk AP with an Ethernet in between. In a N-sector cell, there are N access points and a single wireless hub.

The backhaul network from the base station to the MSC has the following attributes.

1. The network is capable of routing IP datagrams between the base station and the MSC.
2. The network is secure. It is not a public internet. Traffic from trusted nodes only are allowed onto the network since the network will be used for not only transporting end system traffic, but also for transporting authentication, accounting, registration and management traffic.

3. The network has the necessary performance characteristics.

In typical application, the service provider is responsible for installing and maintaining the backhaul network on which the equipment is installed.

The base stations supports the following backhaul interfaces for communicating with the MSC.

1. Base stations support IP over PPP with HDLC links using point to point T1 or fractional T3 links.
2. Base stations support IP over frame relay using T1 or fractional T3 links.
3. Base stations support IP over AAL5/ATM using T1 or fractional T3 links.
4. Base stations support IP over Ethernet links.

Since all of the above interfaces are based on IETF standard encapsulations, commercial routers may be used in the MSC to terminate the physical links of the backhaul network. Higher layers are passed on and processed by the various servers and other processors.

End system registration procedures above the MAC layer are supported. In the following, end system registration procedures at the MAC layer are ignored except where they impact the layers above.

End systems may register for service on their home network or from a foreign network. In both scenarios, the end system uses a foreign agent (FA) in the base station to discover a point of attachment to the network and to register. In the former case, the FA is in the end system's home network. In the latter case, the FA is in a foreign network. In either case, the network uses an IWF in the end system's home network as an anchor point (i.e., unchanging throughout the session in spite of mobility). PPP frames to and from the end system travel via the FA in the base station to the IWF in the home network. If the end system is at home, the home IWF is directly connected by means of the xtunnel protocol to the base station. Note that the home IWF may be combined with the base station in the same node. If the end system is roaming, a serving IWF in the foreign network is connected to the home IWF over an I-interface. The serving IWF relays frames between the base station and the home IWF. Note that the home IWF may be combined with the base station in the same node. From the home IWF, data is sent to a PPP server which may reside in the same IWF or to a separate server using the L2TP protocol. The separate server may be owned and operated by a private network operator (e.g. ISP or corporate intranet) who is different from the wireless service provider. For the duration of the session, the location of the home IWF and the PPP server remains fixed. If the end system moves while connected, it will have to re-register with a new foreign agent. However, the same home IWF and PPP server continues to be used. A new xtunnel is created between the new FA and the IWF and the old xtunnel between the old foreign agent and the IWF is destroyed.

FIG. 12 shows this network configuration for two end systems A and B, both of whose home wireless network is wireless service provider A (WSP-A). One end system is registered from the home wireless network and the other from a foreign wireless network. The home IWF in WSP-A serves as the anchor point for both end systems. For both end systems, data is relayed to the home IWF. The home IWF connects to an internet service provider's PPP server owned by ISP-A. Here it is assumed that both end systems have subscribed to the same ISP. If that were not the case, then the home IWF would be shown also connected to another ISP.

Within a wireless service providers network, data between base stations and the IWF is carried using the xtunnel protocol. Data between the IWF and the PPP server is carried using Level 2 Tunneling Protocol (L2TP). Data between the serving IWF and the home IWF is carried using the I-xtunnel protocol.

In a simple scenerio, for a user in their home network requiring fixed service, the home IWF function may be dynamically activated in the base station. Also, the serving IWF function may be activated for a roaming user in the base station.

Always using an IWF in the home network has its advantages and disadvantages. An obvious advantage is simplicity. A disadvantage is that of always having to relay data to and from a possibly remote home IWF. The alternative is to send all the necessary information to the serving IWF so that it may connect to the end system's ISP/intranet and for the serving IWF to send accounting information in near real time back to the accounting server in the home network. This functionality is more complex to implement, but more efficient because it reduces the need to relay data over potentially long distances from the foreign network to the home network.

For example, consider a case of a user who roams from Chicago to Hong Kong. If the user's home network is in Chicago and the user registers using a wireless service provider in Hong Kong, then in the first configuration, the anchor point will be the home IWF in Chicago and all data will have to be relayed from Hong Kong to Chicago and vice versa. The home IWF in Chicago will connect to the user's ISP in Chicago. With the second configuration, the end system user will be assigned an ISP in Hong Kong. Thus, data will not always have to be relayed back and forth between Chicago and Hong Kong. In the second configuration, the serving IWF will serve as the anchor and never change for the duration of the session even if the end system moves. However, the location of the FA may change as a result of end system movement in Hong Kong.

FIG. 13 shows the second network configuration. In this figure, the home network for end system A and B is WSP-A. End system A registers from its home network, using its home IWF as an anchor point, and also connects to its ISP-A using the ISPs PPP server. End system B registers from the foreign network of WSP-B and uses a serving IWF which serves as the anchor point and connects the end system to an ISP using the ISP's PPP server. In this configuration, data for end system B does not have to be relayed from the foreign network to the home network and vice versa.

In order for this configuration to work, not only must there be roaming agreements between the home and the foreign wireless service providers, but there also must be agreements between the foreign wireless service provider and the end system's internet service provider directly or through an intermediary. In the example above, not only must the wireless service provider in Hong Kong have a business agreement with the wireless service provider in Chicago, but the WSP in Hong Kong must have a business agreement with the user's Chicago ISP and access to the Chicago ISPs PPP server in Hong Kong or a business agreement with another ISP locally in Hong Kong who has a business agreement for roaming with the user's Chicago ISP. Additionally, the WSP in Hong Kong must be able to discover these roaming relationships dynamically in order to do user authentication and accounting and to set up the appropriate tunnels.

It is difficult for those companies who are in the Internet infrastructure business to work out suitable standards in the IETF for all of these scenarios. Thus, a preferable embodiment for the present systems to implement the simpler,

potentially less efficient configuration, where the IWF in the home network is always used as the anchor point. However, in the presence of suitable industry standardization of protocols for Internet roaming, the second configuration should be regarded as equivalent or alternative embodiment.

An end system will have to register with the wireless network before it can start PPP and send and receive data. The end system first goes through the FA discovery and registration phases. These phases authenticate and register the end system to the wireless service provider. Once these phases are over, the end system starts PPP. This includes the PPP link establishment phase, the PPP authentication phase and the PPP network control protocol phase. Once these phases are over, the end system is able to send and receive IP packets using PPP.

The following discussion assumes that the end system is roaming and registering from a foreign network. During the FA discovery phase, the end system (through its user registration agent) waits for or solicits an advertisement from the foreign agent. The user registration agent uses advertisement messages sent by a near by foreign agent to discover the identity of the FA and to register. During this phase, the user registration agent of the end system selects a FA and issues a registration request to it. The FA acting as a proxy registration agent forwards the registration request to its registration server (the registration server in the foreign WSP). The registration server uses User-Name from the user registration agent's request to determine the end system's home network, and forwards the registration request for authentication to a registration server in the home network. Upon receiving the registration request relayed by the foreign registration server, the home registration server authenticates the identity of the foreign registration server and also authenticates the identity of the end system. If authentication and registration succeeds, the home registration server selects an IWF in the home network to create an I-xtunnel link between the home IWF and the serving IWF (in the foreign WSP). The IWF in the home network serves as the anchor point for the duration of the PPP session.

Once the authentication and registration phases are over, the various PPP phases will be started. At the start of PPP, an L2TP connection is created between the home IWF and requested ISP/intranet PPP server. In the PPP authentication phase, PPP passwords using Password Authentication Protocol (PAP) or Challenge Authentication Protocol CHAP are exchanged and the ISP or intranet PPP server independently authenticates the identity of the end system.

Once this succeeds, the PPP network control phase is started. In this phase, an IP address is negotiated and assigned to the end system by the PPP server and the use of TCP/IP header compression is also negotiated. When this is complete, the end system is able to send and receive IP packets using PPP to its ISP or a corporate intranet.

Note that two levels of authentication are performed. The first authentication authenticates the identity of the end system to the registration server in the home network and the identities of the foreign network and the home network to each other. To perform this function, the foreign agent forwards the end system's registration request using, for example, an IETF Radius protocol to a registration server in its local MSC in a Radius Access-Request packet. Using the end system's domain name, the foreign registration server determines the identity of the end system's home network and home registration server, and acting as a Radius proxy, encapsulates and forwards the request to the end system's home registration server. If the foreign registration server cannot determine the identity of the end system's home, it may optionally forward the Radius request to a registration server that acts like a broker (e.g. one that is owned by a consortium of wireless service providers), which can in turn proxy the Radius Access-Request to the final home registration server. If the local registration server is unable to service the registration request locally or by proxying, then it rejects the foreign agent's registration request and the foreign agent rejects the end system's registration request. Upon receiving the Radius Access-Request, the home registration server performs the necessary authentication of the identities of the foreign network and the end system. If authentication and registration succeeds, the home registration server responds with a Radius Access-Response packet to the foreign registration server which sends a response to the foreign agent so that a round trip can be completed. The registration request is rejected if the home registration server is unable to comply for any reason.

The second level of authentication verifies the identity of the end system to the intranet or ISP PPP server. PPP authentication, separate from mobility authentication allows the infrastructure equipment to be deployed and owned separately from the ISP.

FIG. **14** is a ladder diagram showing the registration sequence for a roaming end system. It is assumed that the PPP server and the home IWF are in the same server and L2TP is not required. Note the interactions with accounting servers to start accounting on behalf of the registering end system and also directory servers to determine the identity of the home registration server and to authenticate the end system's identity. More information on accounting, billing, roaming (between service providers) and settlement will be provided below.

MAC layer messages from the user registration agent of the end system may be used to initiate Agent Solicitation. The MAC layer messages are not shown for clarity.

In FIG. **14**, the end system (mobile) initially solicits an advertisement and the foreign agent replies with an advertisement that provides the end system with information about the network to which the foreign agent belongs including a care-of-address of the foreign agent. Alternatively, this phase may be removed and all network advertisements may be done by a continuously emitted MAC layer beacon message. In this case, the network is assumed to be a foreign wireless service provider. Then, a user registration agent (in the end system) incorporates the information about the foreign agent (including the user name and other security credentials) and its network into a request and sends the request to the foreign agent. The foreign agent, as a proxy registration agent, relays the request to the foreign registration server (i.e., the registration server for the foreign wireless service provider. Then, the foreign registration server, recognizing that it is not the home directory, accesses the foreign directory server with the FDD in the foreign wireless service provider to learn how to direct the registration request to the home registration server of the wireless service provider to which the end system belongs. The foreign registration server responds with the necessary forwarding information. Then, the foreign registration server encapsulates the end system's registration request in a Radius access request and relays the encapsulated request to the home registration server of the wireless service provider to which the end system belongs. The home registration server accesses the home directory server with the HDD of the home registration server to learn at least authentication information about the foreign service provider. Optionally, the home registration server accesses the subscriber's directory to learn detail subscriber service profile information

(e.g., quality of service options subscribed to, etc.). When all parties are authenticated, the home registration server sends a start IWF request to the home IWF and PPP server. The home IWF and PPP server starts the home accounting server and then sends a start IWF response to the home registration server. The home registration server then sends a Radius access response to the foreign registration server. The foreign registration server then sends a start IWF request to the serving IWF server. The serving IWF server starts the serving accounting server and then sends a start IWF response to the foreign registration server. The foreign registration server sends a registration reply to the foreign agent, and the foreign agent relays the registration reply to the end system.

A link control protocol (LCP) configuration request is send by the end system through the foreign registration server to the home IWF and PPP server. The home IWF and PPP server sends an LCP configuration acknowledgment through the foreign registration server to the end system.

Similarly, a password authentication protocol (PAP) authentication request is sent to and acknowledged by the home IWF and PPP server. Alternatively, a challenge authentication protocol (CHAP) may be used to authenticate. Both protocols may be used to authenticate or this phase may be skipped.

Similarly, an IP configuration protocol (IPCP) configure request is sent to and acknowledged by the home IWF and PPP server.

The connection to the end system may be terminated because of any one of the following reasons.

1. User initiated termination. Under this scenario, the end system first terminates the PPP gracefully. This includes terminating the PPP network control protocol (IPCP) followed by terminating the PPP link protocol. Once this is done, the end system de-registers from the network followed by termination of the radio link to the access point.
2. Loss of wireless link. This scenario is detected by the modem and reported to the modem driver in the end system. The upper layers of the software are notified to terminate the stacks and notify the user.
3. Loss of connection to the foreign agent. This scenario is detected by the mobility driver in the end system. After trying to re-establish contact with a (potentially new) foreign agent and failing, the driver sends an appropriate notification up the protocol stack and also signals the modem hardware below to terminate the wireless link.
4. Loss of connection to the IWF. This is substantially the same as for loss of connection to the foreign agent.
5. Termination of PPP by IWF or PPP server. This scenario is detected by the PPP software in the end system. The end system's PPP driver is notified of this event. It initiates de-registration from the network followed by termination of the wireless link to the access point.

End system service configuration refers to the concept of configuring the network service for an end system based on the subscriber's service profile. The subscriber's service profile is stored in a subscriber directory. The service profile contains information to enable the software to customize wireless data service on behalf of the subscriber. This includes information to authenticate the end system, allow the end system to roam and set up connections to the end system's internet service provider. Preferably, this information also includes other parameters, like, quality of service.

In addition to the subscriber directory, a home domain directory (HDD) and a foreign domain directory (FDD) are used for roaming and for authenticating the foreign and home registration servers to each other. The HDD stores information about the end system's home network and the FDD stores information about foreign networks that a subscriber may visit.

FIG. **15** shows how these directories map into the network architecture and are used during registration for an end system that is registering at home. In step **0** the end system (mobile) solicits and receives an advertisement from the foreign agent to provides the end system with information about the network to which the foreign agent belongs. In this case, the network is the home wireless service provider. In step **1**, user registration agent (in the end system) incorporates the information about the foreign agent and its network and its security credentials into a request and sends the request to the foreign agent. In step **2**, the foreign agent, as a proxy registration agent, relays the request to the home registration server. In step **3**, the home registration server accesses the HDD of the home wireless service provider to learn at least authentication information. In step **4**, the home registration server accesses the subscriber directory to learn detail subscriber service profile information (e.g., quality of service options subscribed to, etc.). In step **5**, the home registration server notifies the foreign agent of the access response. In steps **6** and **7**, the foreign agent notifies the end system (i.e., mobile) of the registration reply.

FIG. **16** shows directory usage for an end system that is registering from a foreign network. In step **0** the end system (mobile) solicits and receives an advertisement and the foreign agent advertises which provides the end system with information about the network to which the foreign agent belongs. In this case, the network is a foreign wireless service provider. In step **1**, user registration agent (in the end system) incorporates the information about the foreign agent and its network and its security credential into a request and sends the request to the foreign agent. In step **2**, the foreign agent, as a proxy registration agent, relays the request to the foreign registration server (i.e., the registration server for the foreign wireless service provider. In step **3**, the foreign registration server accesses the HDD of foreign wireless service provider to learn the network to which the end system belongs. In step **4**, the foreign registration server forwards the end system's request to the home registration server of the end system's home wireless service provider. In step **5**, the home registration server accesses the FDD of the home registration server to learn at least authentication information about the foreign service provider. In step **6**, the home registration server accesses the subscriber's directory to learn detail subscriber service profile information (e.g., quality of service options subscribed to, etc.). In step **7**, the home registration server notifies the foreign registration server of the access response. In step **8**, the foreign registration server forwards to the foreign agent the access response. In step **9**, the foreign agent notifies the end system (i.e., mobile) of the registration reply.

Protocol handling scenarios handle bearer data and the associated stacks for transporting bearer data to and from an end system. The protocol stacks for the cell architectures use local APs (FIG. **17**) and remote APs (FIG. **18**).

FIG. **17** shows the protocol stacks for handling communications between an end system (in its home network) and a home IWF for End System @ Home. FIG. **17** shows the protocol handling for a cell architecture where the access point and the wireless hub are co-located.

FIG. **18** shows the protocol handling for a cell architecture where the access point is located remotely from the wireless

hub. As shown, PPP terminates in the IWF and the configuration provides direct internet access. The configuration for the case where the PPP server is separate from the IWF is described later.

In FIG. **18**, PPP frames from the end system are encapsulated in RLP (radio link protocol) frames which are encapsulated at the remote access point in MAC frames for communicating with the trunk access point (i.e., an access point physically located near the wireless hub), the remote access point being coupled to the access point by, for example, a wireless trunk). The access point functions as a MAC layer bridge and relays frames from the air link to the foreign agent in the wireless hub. The foreign agent de-encapsulates the RLP frames out of the MAC frames, and using the xtunnel protocol, relays the RLP frames to the IWF. A similar, albeit reverse, process occurs for transmitting frames from the IWF to the end system.

If the end system moves to another foreign agent, then a new xtunnel will be automatically created between the new foreign agent and the IWF, so that PPP traffic continues to flow between them, without interruption.

In the remote AP cell architecture (FIG. **18**) using wireless trunks between the remote AP and the trunk AP, the air link between the end system and the access point may operate at a different frequency (f**1**) and use a different radio technology as compared to the frequency (f**2**) and radio technology of the trunk.

FIG. **19** shows the protocol stacks for a roaming end system. The serving IWF uses of the I-xtunnel protocol between the serving IWF and home IWF. The rest of the protocol stacks remain unchanged and are not shown. This architecture may be simplified by merging the serving IWF into the base station, thus eliminating the XWD protocol.

The RLP layer uses sequence numbers to drop duplicate PPP datagrams and provide in-sequence delivery of PPP datagrams between the end system and the IWF. It also provides a configurable keep-alive mechanism to monitor link connectivity between the end system and the IWF. Additionally, in an alternative embodiment, the RLP layer also provides re-transmission and flow control services in order to reduce the overall bit error rate of the link between the end system and the IWF. The RLP between the end system and the IWF is started at the beginning of the session and remains active throughout the session and even across hand-offs.

In contrast to the specification in the mobile IP RFC (RFC 2003), IP in IP encapsulation is not used for tunneling between the foreign agent and the home IWF. Instead a new tunneling protocol, implemented on top of UDP is used. This tunneling protocol is a simplified version of the L2TP protocol. The reasons for this choice are as follows.

1. The encapsulation protocol specified in RFC 2003 does not provide flow control or in-sequence delivery of packets. The presently described network may need these services in the tunnel over the backhaul. Flow control may be needed to reduce the amount of re-transmissions over the air link because of packet loss due to flow control problems over the network between the base station and the MSC or because of flow control problems in the base station or the IWF.
2. By using a UDP based tunneling protocol, the implementation can be done at the user level and then put into the kernel for performance reasons, after it has been debugged.
3. Using RFC 2003, there is no easy way of creating tunnels taking into account quality of service and load balancing. In order to take QOS into account, it should be possible to set up tunnels over links that already provide the required QOS. Secondly, using RFC 2003, there is no easy way to provide load balancing to distribute bearer traffic load over multiple links between the base station and the MSC.
4. In order to implement IP in IP encapsulation as specified in RFC 2003, developers require access to IP source code. In commercial operating systems, source code for the TCP/IP stack is generally proprietary to other equipment manufacturers. Purchasing the TCP/IP stack from a vendor and making changes to the IP layer to support mobile IP tunneling would require a developer to continue supporting a variant version of the TCP/IP stack. This adds cost and risk.

While it is noted that the tunneling protocol between the base station and the IWF is non-standard and that the wireless service provider will not be able to mix and match equipment from different vendors, the use of a non-standard tunneling protocol within a single wireless service provider network is transparent to end systems and equipment from other vendors.

The new tunneling protocol is based on L2TP. By itself, L2TP is a heavyweight tunneling protocol so that L2TP has a lot of overhead associated with tunnel creation and authentication. The new tunneling protocol of the present system has less overhead. The new xtunnel protocol has the following features.

1. The xtunnel creation adds vendor specific extensions to Radius Access Request and Radius Access Response messages between the base station and the registration server. These extensions negotiate tunnel parameters and to create the tunnel.
2. The registration server is able to delegate the actual work of tunneling and relaying packets to a different IP address, and therefore, to a different server in the MSC. This permits the registration server to do load balancing across multiple IWF servers and to provide different QOS to various users.
3. The xtunnel protocol supports in-band control messages for tunnel management. These messages include echo request/response to test tunnel connectivity, disconnect request/response/notify to disconnect the tunnel and error notify for error notifications. These messages are sent over the tunneling media, for example, UDP/IP.
4. The xtunnel protocol sends payload data over the tunneling media, for example, UDP/IP. The xtunnel protocol supports flow control and in-sequence packet delivery.
5. The xtunnel protocol may be implemented over media other than UDP/IP for quality of service.

The network supports direct internet connectivity by terminating the PPP in the home IWF and routing IP packets from the IWF to the internet via a router using standard IP routing techniques. Preferably, the IWF runs Routing Information Process (RIP), and the router also runs RIP and possibly other routing protocols like Open Shortest Path First (OSPF).

The network supports a first configuration for a wireless service provider who is also an internet service provider. In this configuration, the home IWF in the MSC also functions as a PPP server. This IWF also runs internet routing protocols like RIP and uses a router to connect to the internet service provider's backbone network.

The network supports a second configuration for a wireless service provider who wishes to allow end systems to

connect to one or more internet service providers, either because the WSP itself is not ISPs, or because the WSP has agreements with other ISPs to provide access to end users. For example, a wireless service provider may elect to offer network access to an end user and may have an agreement with a 3^{rd} party ISP to allow the user who also has an account with the 3^{rd} party ISP to access the ISP from the WSP network. In this configuration, the PPP server does not run in the home IWF installed at the MSC. Instead, a tunneling protocol like L2TP (Layer Two Tunneling Protocol) is used to tunnel back to the ISP's PPP server. FIG. **10** shows the protocol stacks for this configuration for an end system that is at home.

The location of the home IWF and the ISP PPP server remains fixed throughout the PPP session. Also, the L2TP tunnel between the IWF and the ISP's PPP server remains up throughout the PPP session. The physical link between the IWF and the PPP server is via a router using a dedicated T1 or T3 or frame relay or ATM network. The actual nature of the physical link is not important from the point of view of the architecture.

This configuration also supports intranet access. For intranet access, the PPP server resides in the corporate intranet and the home IWF uses L2TP to tunnel to it.

For a fixed end system, the protocol handling for intranet or ISP access is as shown in FIG. **20** with the difference that the roaming end system uses a serving IWF to connect to its home IWF. The protocol handling between a serving IWF and a home IWF has been described earlier. In FIG. **20**, the home IWF may be merged into the wireless hub eliminating the X-Tunnel protocol. Also, the serving IWF may be merged into the wireless hub, thus eliminating the X-Tunnel protocol.

FIG. **21** shows the protocol stacks used during the registration phase (end system registration) for a local AP cell architecture. The stack for a remote AP cell architecture is very similar.

The scenario shown above is for a roaming end system. For an end system at home, there is no foreign registration server in the registration path.

Note the mobility agent in the end system. The mobility agent in the end system and foreign agent in the wireless hub are conceptually similar to the mobile IP RFC 2002. The mobility agent handles network errors using time-outs and re-trys. Unlike the known protocol stacks for bearer data, RLP is not used. The foreign agent and the registration servers use Radius over UDP/IP to communicate with each other for registering the end system.

Several aspects of security must be considered. The first, authenticating the identities of the end system and the foreign/home networks during the wireless registration phase. Second, authenticating the identity of the end system with its PPP server during the PPP authentication phase. Third, authentication for storing accounting data, for billing and for updating home domain information. Fourth, encryption of bearer traffic transmitted to and from the end system. Fifth, encryption for exchanging billing information across service provider boundaries.

Shared secrets are used to authenticate the identity of end systems with their home networks and the identity of the home and foreign networks with each other during wireless registration.

End system authentication uses a 128-bit shared secret to create an authenticator for its registration request. The authenticator is created using the known MD5 message digest algorithm as described in the mobile IP RFC 2002. Alternatively, a different algorithm may be used. The shared secret is not sent in the registration request by the end system. Only the authenticator is sent. On receiving the registration request from the end system, the home registration server re-computes the authenticator over the registration request data using the shared secret. If the computed authenticator value matches the authenticator value sent by the end system, the home registration server allows the registration process to proceed. If the values do not match, the home registration server logs the event, generates a security violation alarm and a nak (i.e., a negative acknowledgment) to the request.

In the registration reply, the home registration server does the same—that is to say, uses the shared secret to create an authenticator for the registration reply that it sends to the end system. Upon receiving the reply, the end system re-computes the authenticator using the shared secret. If the computed value does not match the authenticator value sent by the home registration server in the reply, the end system discards the reply and tries again.

These network security concepts are similar to the concepts defined in mobile IP RFC 2002. According to the RFC, a mobility security association exist between each end system and its home network. Each mobility security association defines a collection of security contexts. Each security context defines an authentication algorithm, a mode, a secret (shared or public-private), style of replay protection and the type of encryption to use. In the context of the present network, the end system's User-Name (in lieu of the mobile IP home address) is used to identify the mobility security association between the end system and its home network. Another parameter, called the security parameter index (SPI), is used to select a security context within the mobility security association. In a basic embodiment of the invention, only the default mobile IP authentication algorithm (keyed-MD5) and the default mode ("prefix+suffix") are supported with 128-bit shared secrets. Network users are allowed to define multiple shared secrets with their home networks. The mechanism for creating security contexts for end users, assigning an SPI to each security context and for setting the contents of the security context (which includes the shared secret) and for modifying their contents are described below. During registration, a 128-bit message digest is computed by the end system in prefix+suffix mode using the MD5 algorithm. The shared secret is used as the prefix and the suffix for the data to be protected in the registration request. The authenticator thus computed, along with the SPI and the User-Name are transmitted in the registration request by the end system. Upon receiving the end system's registration request, the foreign registration server relays the request along with the authenticator and the SPI, unchanged to the home registration server. Upon receiving the registration request directly from the end system or indirectly via a foreign registration server, the home registration server uses the SPI and the User-Name to select the security context. The home server re-computes the authenticator using the shared secret. If the computed authenticator value matches the value of the authenticator sent in the request by the end system, the user's identity will have been successfully authenticated. Otherwise, the home registration server naks (negatively acknowledges) the registration request sent by the end system.

The registration reply sent by the home registration server to the end system is also authenticated using the algorithm described above. The SPI and the computed authenticator value is transmitted in the registration reply message by the home server to the end system. Upon receiving the reply, the end system re-computes the authenticator, and if the com-

puted value does not match the transmitted value, it will discard the reply and retry.

The user's end system has to be configured with the shared secret and SPIs for all security contexts that the user shares with its registration server(s). This configuration information is preferably stored in a Win 95 registry for Windows 95 based end systems. During registration, this information is accessed and used for authentication purposes.

In the network, Radius protocols are used by foreign agent FA to register the end system and to configure the xtunnel between the wireless hub and the home and serving IWFs on behalf of the end system. On receiving a registration request from the end system, the FA creates a Radius Access-Request packet, stores its own attributes into the packet, copies the end system's registration request attributes unchanged into this packet and sends the combined request to the registration server in the MSC.

Radius authentication requires that the Radius client (in this case, the FA in the base station) and the Radius server (in this case, the registration server in the MSC) share a secret for authentication purposes. This shared secret is also used to encrypt any private information communicated between the Radius client and the Radius server. The shared secret is a configurable parameter. The network follows the recommendations in the Radius RFC and uses the shared secret and the MD5 algorithm for authentication and for encryption, where encryption is needed. The Radius-Access Request packet sent by the FA contains a Radius User-Name attribute (which is provided by the end system) and a Radius User-Password attribute. The value of the User-Password attribute is also a configurable value and encrypted in the way recommended by the Radius protocol. Other network specific attributes, which are non-standard attributes from the point of view of the Radius RFC standards, are encoded as vendor specific Radius attributes and sent in the Access-Request packet.

The following attributes are sent by the FA to its registration server in the Radius Access-Request packet.

1. User-Name Attribute. This is the end system's username as supplied by the end system in its registration request.
2. User-Password Attribute. This user password is supplied by the base station/wireless hub on behalf of the user. It is encoded as described in the Radius EFC using the secret shared between the base station and its registration server.
3. NAS-Port. This is the port on the base station.
4. NAS-IP-Address. This is the IP address of the base station.
5. Service-Type. This is framed service.
6. Framed Protocol. This is a PPP protocol.
7. Xtunnel Protocol Parameters. These parameters are sent by the base station to specify the parameters necessary to set up the xtunnel protocol on behalf of the end system. This is a vendor-specific attribute.
8. AP-IP-Address. This is the IP address of the AP through which the user is registering. This is a vendor-specific attribute.
9. AP-MAC-Address. This is the MAC address of the AP through which the user is registering. This is a vendor-specific attribute.
10. End system's Registration Request. The registration request from the end system is copied unchanged into this vendor specific attribute.

The following attributes are sent to the FA from the registration server in the Radius Access-Response packet.

1. Service Type. This is a framed service.
2. Framed-Protocol. This is a PPP.
3. Xtunnel Protocol Parameters. These parameters are sent by the registration server to specify the parameters necessary to set up the xtunnel protocol on behalf of the end system. This is a vendor-specific attribute.
4. Home Registration Server's Registration Reply. This attribute is sent to the FA from the home registration server. The FA relays this attribute unchanged to the end system in a registration reply packet. If there is a foreign registration server in the path, this attribute is relayed by it to the FA unchanged. It is coded as a vendor-specific attribute.

To provide service to roaming end systems, the foreign network and the home network are authenticated to each other for accounting and billing purposes using the Radius protocol for authentication and configuration. This authentication is performed at the time of end system registration. As described earlier, when the registration server in the foreign network receives a registration request from an end system (encapsulated as a vendor specific attribute in a Radius-Access Request packet by the FA), it uses the end system's User-Name to determine the identity of the end system's home registration server by consulting its home domain directory HDD. The following information is stored in home domain directory HDD and accessed by the foreign registration server in order to forward the end system's registration request.

1. Home Registration Server IP Address. This is the IP address of the home registration server to forward the registration request.
2. Foreign Registration Server Machine Id. This is the machine ID of the foreign registration server in SMTP (simplified mail transfer protocol) format (e.g., machine@fqdn where machine is the name of the foreign registration server machine and fqdn is the fully qualified domain name of the foreign registration server's domain).
3. Tunneling Protocol Parameters. These are parameters for configuring the tunnel between the serving IWF and the home IWF on behalf of the end system. These include the tunneling protocol to be used between them and the parameters for configuring the tunnel.
4. Shared Secret. This is the shared secret to be used for authentication between the foreign registration server and the home registration server. This secret is used for computing the Radius User-Password attribute in the Radius packet sent by the foreign registration server to the home registration server. It is defined between the two wireless service providers.
5. User-Password. This is the user password to be used on behalf of the roaming end system. This user password is defined between the two wireless service providers. This password is encrypted using the shared secret as described in the Radius RFC.
6. Accounting Parameters. These are parameters for configuring accounting on behalf of the end system that is registering. These parameters are sent by the registration server to its IWF for configuring accounting on behalf of the end system.

Using this information, the foreign registration server creates a Radius Access-Request, adds its own registration and authentication information into the Radius Access-

Request, copies the registration information sent by the end system unchanged into the Radius Access-Request and sends the combined request to the home registration server.

Upon receiving the Radius-Access Request from the foreign registration server (for a roaming end system) or directly from the FA (for an end system at home), the home registration server consults its own directory server for the shared secrets to verify the identity of the end system and the identity of the foreign registration server in a roaming scenario by re-computing authenticators.

After processing the request successfully, the home registration server creates a Radius Access-Accept response packet and sends it to the foreign registration server if the end system is roaming, or directly to the FA from which it received the Radius Access-Request. The response contains the registration reply attribute that the FA relays to the end system.

If the request can not be processed successfully, the home registration server creates a Radius Access-Reject response packet and sends it to the foreign registration server if the end system is roaming, or directly to the FA from which it received the Radius Access-Request. The response contains the registration reply attribute that the FA will relays to the end system.

In a roaming scenario, the response from the home registration server is received by the foreign registration server. It is authenticated by the foreign registration server using the shared secret. After authenticating, the foreign registration server processes the response, and in turn, it generates a Radius response packet (Accept or Reject) to send to the FA. The foreign registration server copies the registration reply attribute from the home registration server's Radius response packet, unchanged, into its Radius response packet.

When the FA receives the Radius Access-Response or Radius Access-Reject response packet, it creates a registration reply packet using the registration reply attributes from the Radius response, and sends the reply to the end system, thus completing the round trip registration sequence.

Mobile IP standards specifies that replay protection for registrations are implemented using time stamps, or optionally, using nonces. However, since replay protection using time stamps requires adequately synchronized time-of-day clocks between the corresponding nodes, the present system implements replay protection during registration using nonces even though replay protection using time stamps is mandatory in the Mobile IP standards and the use nonces is optional. However, replay protection using time stamps as an alternative embodiment is envisioned.

The style of replay protection used between nodes is stored in the security context in addition to the authentication context, mode, secret and type of encryption.

The network supports the use of PPP PAP (password authentication) and CHAP (challenge authenticated password) between the end system and its PPP server. This is done independently of the registration and authentication mechanisms described earlier. This allows a private intranet or an ISP to independently verify the identity of the user.

Authentication for accounting and directory services is described below with respect to accounting security. Access to directory servers from network equipment in the same MSC need not be authenticated.

The network supports encryption of bearer data sent between the end system and the home IWF. End systems negotiate encryption to be on or off by selecting the appropriate security context. Upon receiving the registration request, the home registration server grants the end system's

request for encryption based upon the security context. In addition to storing the authentication algorithm, mode, shared secret and style of replay protection, the security context is also used to specify the style of encryption algorithm to use. If encryption is negotiated between the end system and the home agent, then the complete PPP frame is so encrypted before encapsulation in RLP.

The IWF, the accounting server and the billing system are part of the same trusted domain in the MSC. These entities are either connected on the same LAN or part of a trusted intranet owned and operated by the wireless service provider. Transfer of accounting statistics between the IWF and the accounting server and between the accounting server and the customer's billing system may be encrypted using Internet IP security protocols like IP-Sec.

The network makes it more difficult to monitor the location of the end system because it appears that all PPP frames going to and from the end system go through the home IWF regardless of the actual location of the end system device.

Accounting data is collected by the serving IWF and the home IWF in the network. Accounting data collected by the serving IWF is sent to an accounting server in the serving IWF's MSC. Accounting data collected by the home IWF is sent to an accounting server in the home IWF's MSC. The accounting data collected by the serving IWF is used by the foreign wireless service provider for auditing and for settlement of bills across wireless service provider boundaries (to support roaming and mobility). The accounting data collected by the home IWF is used for billing the end user and also for settlement across wireless service provider boundaries to handle roaming and mobility.

Since all data traffic flows through the home IWF, regardless of the end system's location and the foreign agent's location, the home IWF has all the information to generate bills for the customer and also settlement information for the use of foreign networks.

The serving IWF and the home IWF preferably use the Radius accounting protocol for sending accounting records for registered end systems. The Radius accounting protocol is as documented in a draft IETF RFC. For the present invention, the protocol has to be extended by adding vendor specific attributes for the network and by adding check-pointing to the Radius Accounting protocol. Check-pointing in this context refers to the periodic updating of accounting data to minimize risk of loss of accounting records.

The Radius accounting protocol runs over UDPI/IP and uses re-trys based on acknowledgment and time outs. The Radius accounting client (serving IWFs or home IWFs) send UDP accounting request packets to their accounting servers which send acknowledgments back to the accounting clients.

In the network, the accounting clients (serving IWF and the home IWF) emit an accounting start indication at the start of the user's session and an accounting stop indication at the end of the user's session. In the middle of the session, the accounting clients emit accounting checkpoint indications. In contrast, the Radius accounting RFC does not specify an accounting checkpoint indication. The software of the present system creates a vendor specific accounting attribute for this purpose. This accounting attribute is present in all Radius Accounting-Request packets which have Acct-Status-Type of Start (accounting start indications). The value of this attribute is used to convey to the accounting server whether the accounting record is a check-pointing record or not. Check-pointing accounting reports have a time attribute and contain cumulative accounting data from the start of the

session. The frequency of transmitting check-point packets is configurable in the present invention.

The serving IWF and the home IWF are configured by their respective registration servers for connecting to their accounting servers during the registration phase. The configurable accounting parameters include the IP address and UDP port of the accounting server, the frequency of check-pointing, the session/multi-session id and the shared secret to be used between the accounting client and the accounting server.

The network records the following accounting attributes for each registered end system. These accounting attributes are reported in Radius accounting packets at the start of the session, at the end of the session and in the middle (check-point) by accounting clients to their accounting servers.

1. User Name. This is like the Radius User-Name attribute discussed above. This attribute is used to identify the user and is present in all accounting reports. The format is "user@domain" where domain is the fully qualified domain name of the user's home.
2. NAS IP Address . This is like the Radius NAS-IP-Address attribute discussed above. This attribute is used to identify the IP address of the machine running the home IWF or the serving IWF.
3. Radio Port. This attribute identifies the radio port on the access point providing service to the user. This attribute is encoded as a vendor specific attribute.
4. Access Point IP Address. This attribute identifies the IP address of the access point providing service to the user. This attribute is encoded as a vendor specific attribute.
5. Service Type. This is like the Radius Service-Type attribute described above. The value of this attribute is Framed.
6. Framed Protocol. This is like the Radius Framed-Protocol attribute described above. The value of this attribute is set to indicate PPP.
7. Accounting Status Type. This is like the Radius Acct-Status-Type attribute described above. The value of this attribute may be Start to mark the start of a user's session with the Radius client and Stop to mark the end of the user's session with the Radius client. For accounting clients, the Acct-Status-Type/Start attribute is generated when the end system registers. The Acct-Status-type/Stop attribute is generated when the end system de-registers for any reason. For checkpoints, the value of this attribute is also Start and the Accounting Checkpoint attribute is also present.
8. Accounting Session Id. This is like the Radius Acct-Session-Id described above. In a roaming scenario, this session id is assigned by the foreign registration server when the end system issues a registration request. It is communicated to the home registration server by the foreign registration server during the registration sequence. The home network and the foreign network both know the Acct-Session-Id attribute and are able to emit this attribute while sending accounting records to their respective accounting servers. In a "end system-at-home" scenario, this attribute is generated by the home registration server. The registration server communicates the value of this attribute to the IWF which emits it in all accounting records.
9. Accounting Multi-Session Id. This is like the Radius Acct-Multi-Session-Id discussed above. This id is assigned by the home registration server when a registration request is received from a FA directly or via a foreign registration server on behalf of an end system. It is communicated to the foreign registration server by the home registration server in the registration reply message. The registration server(s) communicates the value of this attribute to the IWF(s) which emit it in all accounting records.

With true mobility added to the architecture, the id is used to relate together the accounting records from different IWFs for the same end system if the end system moves from one IWF to another. For hand-offs across IWF boundaries, the Acct-Session-Id is different for accounting records emanating from different IWFs. However, the Acct-Multi-Session-Id attribute is the same for accounting records emitted by all IWFs that have provided service to the user. Since the session id and the multi-session id are known to both the foreign network and the home network, they are able to emit these attributes in accounting reports to their respective accounting servers. With the session id and the multi-session id, billing systems are able to correlate accounting records across IWF boundaries in the same wireless service provider and even across wireless service provider boundaries.

1. Accounting Delay Time. See Radius Acct-Delay-Time attribute.
2. Accounting Input Octets. See Radius Acct-Input-Octets. This attribute is used to keep track of the number of octets sent by the end system (input to the network from the end system). This count is used to track the PPP frames only. The air link overhead, or any overhead imposed by RLP, etc. is not counted.
3. Accounting Output Octets. See Radius Acct-Output-Octets. This attribute is used to keep track of the number of octets sent to the end system (output from the network to the end system). This count is used to track the PPP frames only. The air link overhead, or any overhead imposed by RLP, etc. and is not counted.
4. Accounting Authentic. See Radius Acct-Authentic attribute. The value of this attribute is Local or Remote depending on whether the serving IWF or the home IWF generates the accounting record.
5. Accounting Session Time. See Radius Acct-Session-Time attribute. This attribute indicates the amount of time that the user has been receiving service. If sent by the serving IWF, this attribute tracks the amount of time that the user has been receiving service from that serving IWF. If sent by the home IWF, this attribute tracks the amount of time that the user has been receiving service from the home IWF.
6. Accounting Input Packets. See Radius Acct-Input-Packets attribute. This attribute indicates the number of packets received from the end system. For a serving IWF, this attribute tracks the number of PPP frames input into the serving IWF from an end system. For a home IWF, this attribute tracks the number of PPP frames input into the home IWF from an end system.
7. Accounting Output Packets. See Radius Acct-Output-Packets attribute. This attribute indicates the number of packets sent to the end system. For a serving IWF, this attribute tracks the number of PPP frames output by the serving IWF to the end system. For a home IWF, this attribute tracks the number of PPP frames sent to the end system from the home IWF.
8. Accounting Terminate Cause. See Radius Acct-Terminate-Cause attribute. This attribute indicates the reason why a user session was terminated. In addition, a specific cause code is also present to provide additional details. This attribute is only present in accounting reports at the end of the session.

9. Network Accounting Terminate Cause. This attribute indicates a detailed reason for terminating a session. This specific attribute is encoded as a vendor specific attribute and is only reported in a Radius Accounting attribute at the end of session. The standard Radius attribute Acct-Terminate-Cause is also present. This attribute provides specific cause codes, not covered by the Acct-Terminate-Cause attribute.
10. Network Air link Access Protocol. This attribute indicates the air link access protocol used by the end system. This attribute is encoded as a vendor specific attribute.
11. Network Backhaul Access Protocol. This attribute indicates the backhaul access protocol used by the access point to ferry data to and from the end system. This attribute is encoded as a vendor specific attribute.
12. Network Agent Machine Name. This attribute is the fully qualified domain name of the machine running the home IWF or the serving IWF. This specific attribute is encoded in vendor specific format.
13. Network Accounting Check-point. Since the Radius accounting RFC does not define a check-point packet, the present network embodiment uses a Radius accounting start packet with this attribute to mark a check-point. The absence of a check-point attribute means a conventional accounting start packet. The presence of this attribute in a accounting start packet means a accounting check-point packet. Accounting stop packets do not have this attribute.

In the preferred embodiment, every accounting packet and the corresponding reply must be authenticated using MD5 and a shared secret. The IWFs are configured with a shared secret that are used by them for authentication during communication with their Radius accounting server. The shared secrets used by the IWFs for communicating with accounting servers are stored in the home/foreign domain directory located in the MSC. The shared secrets for accounting security are communicated to the IWFs by their registration servers during the end system registration sequence.

The accounting server software runs in a computer located in the MSC. The role of the accounting server in the system is to collect raw accounting data from the network elements (the home and the serving IWFs), process the data and store it for transfer to the wireless service provider's billing system. The accounting server does not include a billing system. Instead, it includes support for an automatic or manual accounting data transfer mechanism. Using the automatic accounting data transfer mechanism, the accounting server transfers accounting records in AMA billing format to the customer's billing system over a TCP/IP transport. For this purpose, the system defines AMA billing record formats for packet data. Using the manual transfer mechanism, customers are able to build a tape to transfer accounting records to their billing system. In order to build the tape to their specifications, customers are provided with information to access accounting records so that they may process them before writing them to tape.

In FIG. **22**, the raw accounting data received by the accounting server from the home or serving IWFs are processed and stored by the accounting server. The processing done by the accounting server includes filtering, compression and correlation of the raw accounting data received from the IWF. A high availability file server using dual active/standby processors and hot swappable RAID disks is used for buffering the accounting data while it is transiting through the accounting server.

The accounting server delays processing of the raw accounting data until an end system has terminated its session. When an end system terminates its session, the accounting server processes the raw accounting data that it has collected for the session and stores an accounting summary record in a SQL database. The accounting summary record stored in the SQL data base points to an ASN.1 encoded file. This file contains detailed accounting information about the end system's session. The data stored in the accounting server is then transferred by the billing data transfer agent to the customer's billing system. Alternatively, the wireless service provider may transfer the accounting data from the SQL database and/or the ASN.1 encoded file to the billing system via a tape. The data base scheme and the format of the ASN.1 encoded file are documented and made available to customers for this purpose. If the volume of processed accounting data stored in the accounting system exceeds a high water mark, the accounting server generates an NMS alarm. This alarm is cleared when the volume of data stored in the accounting server falls below a low water mark. The high and low water marks for generating and clearing the alarm are configurable. The accounting server also generates an NMS alarm if the age of the stored accounting data exceeds a configurable threshold. Conversely, the alarm is cleared, when the age of the accounting data falls below the threshold.

The subscriber directory is used to store information about subscribers and is located in the home network. The home registration server consults this directory during the registration phase to authenticate and register an end system. For each subscriber, the subscriber directory stores the following information.

1. User-Name. This field in the subscriber record will be in SMTP format (e.g., user@fqdn) where the user sub-field will identify the subscriber in his or her wireless home domain and the fqdn sub-field will identify the wireless home domain of the subscriber. This field is sent by the end system in its registration request during the registration phase. This field is assigned by the wireless service provider to the subscriber at the time of subscription to the network service. This field is different than the user name field used in PPP.
2. Mobility Security Association. This field in the subscriber record contains the mobility security association between the subscriber and his or her home network. As described above, a mobility security association exists between each subscriber and its home registration server. The mobility security association defines a collection of security contexts. Each security context defines an authentication algorithm, an authentication mode, a shared secret, style of replay protection and the type of encryption (including no encryption) to use between the end system and its home server. During registration, the home registration server retrieves information about the subscriber's security context from the subscriber directory using the User-Name and the security parameter index (SPI) supplied by the end system in its registration request. The information in the security context is used for enforcing authentication, encryption and replay protection during the session. The mobility security association is created by the wireless service provider at the time of subscription. It is up to the wireless service provider to permit the subscriber to modify this association either by calling up a customer service representative or by letting subscribers access to a secure Web site. The Web

site software will export web pages which the wireless service provider may make accessible to subscribers from a secure web server. In this way, subscribers are able to view/modify the contents of the mobility security association in addition to other subscriber information that the service provider may make accessible.

3. Modem MAC Address. This field contains the MAC address of the modem owned by the subscriber. In addition to the shared secret, this field is used during registration to authenticate the user. It is possible to turn off MAC address based authentication on a per user basis. The MAC address is communicated to the home registration server during registration.
4. Enable MAC Address Authentication. This field is used to determine if MAC address based authentication is enabled or disabled. If enabled, the home registration server checks the MAC address of the registering end system against this field to validate the end system's identity. If disabled, then no checking is done.
5. Roaming Enabled Flag. If this field is set to enabled, then the end system is allowed to roam to foreign networks. If this field is disabled, then the end system is not permitted to roam to foreign networks.
6. Roaming Domain List. This field is meaningful only if the Roaming Enabled Flag is set to enabled. This field contains a list of foreign domains that the end system is allowed to roam to. When the contents of this list is null and the Roaming Enabled Flag is set to enabled, the end system is allowed to roam freely.
7. Service Enable/Disable Flag. This field may be set to disabled by the system administrator to disable service to a subscriber. If this field is disabled, then the subscriber is permitted to register for service. If the subscriber is registered and the value of this field is set to disabled, then the subscriber's end system is immediately disconnected by the network.
8. Internet Service Provider Association. This field contains information about the subscriber's internet service provider. This information is used by the IWF during the PPP registration phase to perform authentication with the internet service provider on behalf of the end system and also to create a L2TP tunnel between the IWF and the internet service provider's PPP server. This field contains the identity of the subscriber's ISP. The IWF uses this information to access the ISP directory for performing authentication and setting up the L2TP tunnel on behalf of the end system.
9. Subscriber's Name & Address Information. This field contains the subscriber's name, address, phone, fax, e-mail address, etc.

The home domain directory (HDD) is used by the registration server to retrieve parameters about the end system to complete registration on behalf of the end system. Using this information, the registration server determines if the end system is registering at home or if the end system is a roaming end system. In the former case, the registration server assumes the role of a home registration server and proceed with end system registration. In the latter case, the registration server assumes the role of a foreign registration server and, acting as a Radius proxy, it forwards the request to the real home registration server whose identity it gets from this directory. For roaming end system, the parameters stored in the HDD include the IP address of the home registration server, the home-foreign shared secret, the home-serving IWF tunnel configuration etc. The HDD is located in the MSC.

The following information is stored in the HDD.

1. Home Domain Name. This field is used as the key to search the HDD for an entry that matches the fully qualified home domain name provided by the end system in its registration request.
2. Proxy Registration Request. This field is used by the registration server to determine if it should act as a foreign registration server and proxy the end system's registration request to the real home registration server.
3. Home Registration Server DNS Name. If the proxy registration request flag is TRUE, this field is used to access the DNS name of the real home registration server. Otherwise, this field is ignored. The DNS name is translated to an IP address by the foreign registration server. The foreign registration server uses the IP address to relay the end system's registration request.
4. Foreign Domain Name. If the proxy registration request flag is TRUE, this field is used to identify the foreign domain name to the end system's home registration server. Otherwise, this field is ignored. The foreign registration server uses this information to create the foreign server machine id in SMTP format, for example, machine@fqdn. This machine id is sent to the home registration server by the foreign registration server in the Radius-Access Request.
5. Shared Secret. If the proxy registration request flag is TRUE, the shared secret is used between the foreign and home registration servers to authenticate their identity with each other. Otherwise this field is ignored.
6. Tunneling Protocol Parameters. This field is used to store parameters to configure the tunnels to provide service to the end system. For an end system at home, this includes information on tunnel parameters between the base station and the home IWF and from the home IWF to the PPP server. For a roaming end system, this includes tunneling parameters from the base station to the serving IWF and from the serving IWF to the home IWF. At a minimum, for each tunnel, this field contains the type of tunneling protocol to use and any tunneling protocol specific parameters. For example, this field may contain the identifier for the tunneling protocol L2TP and any additional parameters required to configure the L2TP tunnel between the IWF and its peer.
7. Accounting Server Association. This field is used to store information needed by the IWF to generate accounting data on behalf of the end system. It contains the name of the accounting protocol (e.g. RADIUS), the DNS name of the accounting server and additional parameters specific to the accounting protocol like the UDP port number, the shared secret that the IWF must use in the Radius Accounting protocol, the frequency of check-pointing, the seed for creating the session/multi-session id, etc. The accounting server's DNS name is translated to the accounting server's IP address, which is sent to the IWF.

For wireless service providers that have roaming agreements with each other, the HDD is used for authentication and to complete the registration process. If an end system roams from its home network to a foreign network, the foreign registration server in that network consults the HDD in its MSC to get information about the visiting end system's home registration and to authenticate the home network before it provides service to the visiting end system.

The software for home domain directory management preferably provides a graphical user interface (GUI) based HDD management interface for system administrators.

Using this GUI, system administrators are able to view and update entries in the HDD. This GUI is not intended for use by foreign wireless network service providers to perform remote updates based on roaming agreements. It is only intended for use by trusted personnel of the home wireless service provider operating behind fire walls.

The foreign domain directory (FDD) provides functionality that is the reverse of the home domain directory. The FDD is used by the home registration server to retrieve parameters about the foreign registration server and the foreign network in order to authenticate the foreign network and create a tunnel between a serving IWF and a home IWF. These parameters include the home-foreign shared secret, the home IWF-serving IWF tunnel configuration, etc. The FDD is preferably located in the home registration server's MSC. The FDD is used by home registration servers for registering roaming end systems.

The following information will be stored in the FDD.

1. Foreign Domain Name. This field is used as the key to search the FDD for an entry that matches the fully qualified domain name of the foreign registration server relaying the registration request.
2. Shared Secret. This is the shared secret used between the foreign and home registration servers to authenticate their identity mutually with each other.
3. Home IWF-Serving IWF Tunneling Protocol Parameters. This field is used to store parameters to configure the tunnel between the home IWF and the serving IWF. At a minimum, this field contains the type of tunneling protocol to use and any tunneling protocol specific parameters. For example, this field may contain the identifier for the tunneling protocol L2TP and any additional parameters required to configure the L2TP tunnel between the serving IWF and the home IWF.
4. Accounting Server Association. This field is used to store information needed by the home IWF to generate accounting data on behalf of the end system. It contains the name of the accounting protocol (e.g. RADIUS), the DNS name of the accounting server and additional parameters specific to the accounting protocol like the UDP port number, the shared secret that the IWF must use in the Radius Accounting protocol, the frequency of check-pointing, the seed for creating the session/multi-session id, etc. The accounting server's DNS name is translated to the accounting server's IP address, which is sent to the foreign agent.

For wireless service providers that have roaming agreements with each other, the FDD is used to do authentication and complete the registration process. If an end system roams from its home network to a foreign network, the registration server in the home network consults the FDD in its MSC to get information and authenticate the foreign network providing service to the end system.

The foreign domain directory management software provides a graphical user interface (GUI) based FDD management interface for system administrators. Using this GUI, system administrators are able to view and update entries in the FDD. This GUI is not intended for use by foreign wireless network service providers to perform remote updates based on roaming agreements. It is only intended for use by trusted personnel of the home wireless service provider operating behind firewalls.

The internet service provider directory (ISPD) is used by the home IWF to manage connectivity with ISPs that have service agreements with the wireless service provider so that subscribers may access their ISPs using the network. For each subscriber, the subscriber directory has an entry for the subscriber's ISP. This field points to an entry in the ISPD. The home IWF uses this information to set up the connection to the ISP on behalf of the subscriber.

The network architecture supports roaming. In order for roaming to work between wireless service providers, the architecture must support the setting up of roaming agreements between wireless service providers. This implies two things: (1) updating system directories across wireless service providers and (2) settlement of bills between service providers.

In order to allow subscribers access to internet service providers, the architecture supports roaming agreements with internet service providers. This implies that the architecture must be able to send data to and receive data from ISP PPP servers (i.e., that support industry standard protocols like PPP, L2TP and Radius). It also implies that the architecture handles directory updates for ISP access and settlement of bills with ISPs.

When roaming agreements are established between two wireless service providers, both providers have to update their home and foreign domain directories in order to support authentication and registration functions for end systems visiting their networks from the other network. At a minimum, the architecture of the present embodiment supports manual directory updates. When a roaming agreement is established between two wireless service providers, then the two parties to the agreement exchange information for populating their home and foreign domain directories. The actual updates of the directories is done manually by the personnel of the respective service providers. If later, the information in the home and foreign domain directories needs to be updated, the two parties to the agreement exchange the updated information and then manually apply their updates to the directories.

In an alternative embodiment, the directory management software incorporates developing standards in the IETF to enable roaming between internet service providers and to enable ISPs to automatically manage and discover roaming relationships. This makes manual directory management no longer necessary. The network system automatically propagates roaming relationships, and discovers them, to authenticate and register visiting end systems.

At a minimum, the network architecture just processes and stores the accounting data and makes the data available to the wireless service provider's billing system. It is up to the billing system to handle settlement of bills for roaming.

In an alternative embodiment, developing standards in the IETF to handle distribution of accounting records between internet service providers are incorporated into the network architecture to enable ISPs to do billing settlement for roaming end systems.

The system software supports access to ISPs and private intranets by supporting L2TP between the home IWF and the ISPs or intranet PPP server. The internet service provider directory contains information useful to the IWF for creating these tunnels. As access agreements between the wireless service provider and internet service providers are put in place, this directory is updated manually by the wireless service provider's personnel. Automatic updates and discovery of access relationships between the wireless service provider and internet service providers are presently contemplated and implemented as the internet standards evolve. While accessing an internet service provider, the subscriber receives two bills—one from the wireless service provider for the use of the wireless network and the second from the internet service provider. Although common billing that combines both types of charges is not handled by the

minimum embodiment software, it is contemplated that the software will take advantage of internet standards for billing settlement as they evolve so that subscribers may receive a common bill based on roaming agreements between the ISP and wireless service providers.

The system includes a element management system for managing the network elements. From the element manager, system administrators perform configuration, performance and fault/alarm management functions. The element management applications run on top of a web browser. Using a web browser, system administrators manage the network from anywhere that they have TCP/IP access. The element manager also performs an agent role for a higher level manager. In this role it exports an SNMP MIB for alarm and fault monitoring.

A higher level SNMP manager is notified of alarm conditions via SNMP traps. The higher level SNMP manager periodically polls the element manager's MIB for the health and status of the network. System management personnel at the higher level manager are able to view an icon representation of the network and its current alarm state. By pointing and clicking on the network element icon, systems management personnel execute element management applications using a web browser and perform more detailed management functions.

Inside the network, management of the physical and logical network elements is performed using a combination of the SNMP protocol and internal management application programming interfaces. Applications in the element manager use SNMP or other management APIs to perform network management functions.

Architecturally, the element management system includes two distinct sets of functional elements. The first set of functional elements, including the configuration data server, performance data monitor and health/status monitor and network element recovery software, executes on an HA server equipped with RAID disks. The second set of functional elements, including the management applications, executes on a dedicated, non-HA management system. Even if the element manager system becomes non-operational, the network elements continue to be able to run and report alarms and even be able to recover from fault conditions. However, since all the management applications execute in the non-HA element manager, if the element manager goes down, then recovery actions requiring human intervention are not possible until the element manager becomes operational.

The wireless hubs (WHs) in the base stations are typically owned by a wireless service provider (WSP), and they are connected to the WSP's registration server (RS) either via point-to-point links, intranets or the Internet. The WSP's registration server is typically a software module executing on a processor to perform certain registration functions. Inter-working function units (IWF units) are typically software modules executing on a processor to perform certain interfacing functions. IWF units are typically connected to the registration servers via intranets/WAN, and the IWF units are typically owned by the WSP. However, the IWF units need not be located within the same LAN as the registration servers. Typically, accounting and directory servers (also software modules executing on a processor) are connected to the registration servers via a LAN in the service provider's Data Center (e.g., a center including one or more processors that hosts various servers and other software modules). Traffic from the end system is then routed via a router (connected to the LAN) to the public Internet or to an ISP's intranet.

The registration server located in a foreign WSP's network is referred to as the foreign registration server (FRS), and the registration server located in the end system's home network (where the mobile purchases its service) is referred to as the home registration server (HRS). The inter-working function unit in the home network is referred to as the home IWF while the inter-working function unit in the foreign network (i.e., the network the end system is visiting) is referred to as the serving IWF.

For fixed wireless service (i.e., a non-moving end system), an end system may register for service on the home network from the home network (e.g., at home service) or from a foreign network (e.g., roaming service). The end system receives an advertisement sent by an agent (e.g., an agent function implemented in software) in the wireless hub via the access point. There are both MAC-layer registration as well as network-layer registration to be accomplished. These may be combined together for efficiency.

For end systems at home (FIG. **23**), the network layer registration (like a local registration) make's known to the home registration server the wireless hub to which the end system is currently attached. An IWF in the end system's home network will become the anchor or home IWF. Thus, PPP frames to and from the end system travel via the wireless hub to the home IWF in the home network. If the end system is at home, the home IWF is connected to the wireless hub via an XTunnel protocol.

For roaming wireless service (FIG. **24**), the foreign registration server determines the identity of the home network of the roaming end system during the registration phase. Using this information, the foreign registration server communicates with the home registration server to authenticate and register the end system. The foreign registration server then assigns a serving IWF, and an I-XTunnel protocol connection is established between the home IWF and the serving IWF for the roaming end system. The serving IWF relays frames between the wireless hub and the home IWF. From the home IWF, data is sent to a PPP server (i.e., point-to-point protocol server) which may reside in the same IWF. However, if the data is to go to a corporate intranet or an ISP's intranet that has its own PPP server, the data is sent to the separate PPP server via the L2TP protocol. The separate server is typically owned and operated by an Internet service provider who is different from the wireless service provider. For the duration of the session, the locations of the home IWF and PPP server remain fixed. The MAC layer registration can be combined with the network registration to economize on the overhead of separate communications for MAC layer and network layer registration; however, it may be advantageous to not combine these registration processes so that the WSP's equipment will be interoperable with other wireless networks that supports pure IETF Mobile-IP.

Registration sets up three tables. Table 1 is associated with each access point, and Table 1 identifies each connection (e.g., each end system) by a connection id (CID) and associates the connection id with a particular wireless (WM) modem address (i.e., the address of the end system or end system). Table 2 is associated with each wireless hub (WH), and Table 2 associates each connection id with a corresponding wireless modem address, access point and XTunnel id (XID). Table 3 is associated with each inter-working function (IWF), and Table 3 associates each connection id with a corresponding wireless modem address, wireless hub address, XTunnel id and IP port (IP/port). The entries described for these tables are described to include only relevant entries that support the discussion of mobility

management. In reality, there are other important fields that need to be included as well.

TABLE 1

Connection Table at AP

CID	WM
C1	WM1
C2	WM1
C1	WM2

TABLE 2

Connection Table at WH

CID	WM	AP	XID
C1	WM1	AP1	5
C2	WM1	AP1	5
C1	WM2	AP1	6
C1	WM3	AP2	7

TABLE 3

Connection Table at IWF

CID	WM	WH	XID	IP/Port
C1	WM1	WH1	5	IP1/P1
C2	WM1	WH1	5	IP1/P2
C1	WM2	WH1	6	IP2/P3
C1	WM3	WH1	7	IP3/P1
C5	WM5	WH2	8	IP4/P1

The protocol stacks for dial-up users at home in a network as well as roaming users are illustrated in FIGS. **25**–**28**. FIG. **25** depicts protocol stacks used for direct internet access by a fixed (i.e., non-moving) end system at home where a PPP protocol message terminates in the home IWF (typically collocated with the wireless hub) which relays message to and from an IP router and from there to the public internet. FIG. **26** depicts protocol stacks used for remote intranet access (i.e., either private corporate nets or an ISP) by a fixed (i.e., non-moving) end system at home where a PPP protocol message is relayed through the home IWF (typically collocated with the wireless hub) to a PPP server of the private corporate intranet or ISP. FIG. **27** depicts protocol stacks used for direct internet access by a roaming but fixed (i.e., non-moving) or a moving end system where the PPP protocol terminates in the home IWF (typically located in a mobile switching center of the home network) which relays message to and from an IP router. In FIG. **27**, note how message traffic passes through a serving IWF (typically collocated with the wireless hub) in addition to the home IWF. FIG. **28** depicts protocol stacks used for remote intranet access (i.e., either private corporate nets or an ISP) by a roaming but fixed (i.e., non-moving) or a moving end system where a PPP protocol message is relayed through the home IWF (typically located in a mobile switching center of the home network) to a PPP server of the private corporate intranet or ISP. In FIG. **28**, note how message traffic passes through a serving IWF (typically collocated with the wireless hub) in addition to the home IWF. When the serving IWF and the wireless hub are co-located in the same nest of computers or are even programmed into the same computer, it is not necessary to establish a tunnel using the XTunnel protocol between the serving IWF and the wireless hub.

Equivalent variations to these protocol stacks (e.g. the RLP can be terminated at the wireless hub rather than at the serving IWF or home IWF for mobiles at home) are also envisioned. If the IWF is located far from the wireless hub, and the packets can potentially be carried over a lossy IP network between the IWF and wireless hub, then it would be preferred to terminate the RLP protocol at the wireless hub. Another variation is the Xtunnel between wireless hub and IWF need not be built on top of the UDP/IP. Xtunnels can be built using the Frame Relay/ATM link layer. However, the use of UDP/IP makes it easier to move the wireless hub and IWF software from one network to another.

Furthermore, the PPP protocol can be terminated in a wireless modem and sent to one or more endsystems via an ethernet connection. As illustrated in FIG. **29**, the wireless modem **300** receives the PPP protocol information and encapsulates the PPP payload in an ethernet frame to be transported to at least one of the end systems **304** and **306** via the internet connection **302**.

DIX ethernet can be used for encapsulating the XWD MAC primitives but the invention is not limited thereto. The ethernet frame format for XWD control frames is illustrated in FIG. **30**. The ethernet header contains a destination address, a source address and an ethernet type field. The destination address field contains the ethernet address of the MAC entity to which the primative is being sent. For MAC primitives invoked by the MAC user, this field will contain the ethernet address of the MAC user. For broadcast primitives, this address will be the ethernet broadcast address. The source address field contains the ethernet address of the MAC entity invoking the primitive. The ethernet type field contains the ethernet type for XWD. Possible values are XWD_Control for control frames and XWD_Data for data frames. These values must be different from all the ethernet type values that have been stnadardized and must be registered with the controlling authority.

The ethernet frame then has an XWD header field. The XWD header can be 16 bits long and will only be present for XWD control frames. The fields are illustrated in FIG. **31**. The ethernet frame also contains a protocol header, a PPP payload field and a XWD MAC field. The header values for primitives using ethernet encapsulation are illustrated in Table 4 below.

Primitive Name	Destination Address	Source Address	Ethernet Type	XWD MAC Primitive
M_Discover.Req	Broadcast or unicast MAC Providider	MAC User	XWD_Control	0
M_Discover.Cnf	MAC User	MAC Provider	XWD_Control	1
M_OpenSap.Req	MAC Provider	MAC User	XWD_Control	2
M_OpenSap.Cnf	MAC User	MAC Provider	XWD_Control	3
M_CloseSap.Req	MAC Provider	MAC User	XWD_Control	4

-continued

Primitive Name	Destination Address	Source Address	Ethernet Type	XWD MAC Primitive
M_CloseSap.Cnf	MAC User	MAC Provider	XWD_Control	5
M_EchoSap.Req	MAC User	MAC Provider	XWD_Control	6
M_EchoSap.Cnf	MAC Provider	MAC User	XWD_Control	7
M_Connect.Req	MAC Provider (modem only)	MAC User (end system only)	XWD_Control	8
M_Connect.Ind	MAC User (wireless hub only)	MAC Provider (AP only)	XWD_Control	9
M_Connect.Rsp	MAC Provider (AP only)	MAC User (wireless hub only)	XWD_Control	10
M_Connect.Cnf	MAC User (end system only)	MAC Provider (modem only)	XWD_Control	11
M_Disconect.Req	MAC Provider	MAC User	XWD_Control	12

In another alternative, the PPP protocol can be terminated in a wireless router and then sent on to at least one end system connected to a local area network (LAN). As illustrated in FIG. **32**, the wireless router **350** receives the PPP protocol information via the wireless modem **352**. The router **354** receives the PPP information from the wireless modem **352** and sends the PPP information to at least one of the end systems **356**, **358**, **360** via a LAN link **362**.

Four types of handoff scenarios may occur, and they are labeled: (i) local mobility, (ii) micro mobility, (iii) macro mobility, and (iv) global mobility. In all four scenarios (in one embodiment of the invention), a route optimization option is not considered so that the locations of the home registration server and the ISP's PPP server do not change. In another embodiment of the system with route optimization, the ISP's PPP server may change. However, this aspect is discussed below. In addition, the locations of the foreign registration server and IWF do not change in the first three scenarios.

The proposed IETF Mobile IP standard requires that whenever an end system changes the IP subnet to which it is attached, it sends a registration request message to a home agent in its home subnet. This message carries a care-of address where the end system can be reached in the new subnet. When traffic is sent, for example, from an ISP to an end system, the home agent intercepts the traffic that is bound for the end system as it arrives in the home subnet, and then forwards the traffic to the care-of address. The care-of address identifies a particular foreign agent in the foreign subnet. An end system's foreign agent can reside in the end system itself, or in a separate node that in turn forwards traffic to the end system (i.e., proxy registration agent). Mobile IP handoffs involve exchange of control messages between an end system's agent, the end system's home agent and potentially its corresponding hosts (CHs) (with route optimization option).

The proposed IETF Mobile IP standard would find it difficult to meet the latency and scalability goals for all movements in a large internetwork. However, the present hierarchical mobility management meets such goals. For small movements (e.g. a change of Access Points), only MAC-layer re-registrations are needed. For larger movements, network-layer re-registrations are performed. The present hierarchical mobility management is different from the flat-structure used in the IETF proposed Mobile-IP standard as well as the serving/anchor inter-working function model used in cellular systems like CDPD (based on a standard sponsored by the Cellular Digital Packet Data forum).

As depicted in FIG. **33**, the local mobility handoff handles end system (designated MN for mobile node) movement between APs that belong to the same wireless hub. Thus, only MAC layer re-registration is required. The end system receives a wireless hub advertisement from a new AP and responds with a registration request addressed to the new AP.

The new AP (i.e., the one that receives the registration request from the end system) creates new entries in its connection table and relays the registration message to its wireless hub. In local mobility handoffs, the wireless hub does not change. The wireless hub recognizes the end system's registration request as a MAC level registration request, and it updates its connection table to reflect the connection to the new AP. Then, the old AP deletes the connection entry from its connection table. There are at least three ways whereby the old AP can delete the old entries, namely (i) upon time out, (ii) upon receiving a copy of the relayed MAC layer association message from the new AP to the wireless hub (if this relay message is a broadcast message), and (iii) upon being informed by the wireless hub of the need to delete the entry.

As depicted in FIG. **34**, the micro mobility handoff handles end system (designated MN for mobile node) movement between wireless hubs that belong to the same registration server and where the end system can still be served by the existing serving IWF. When an advertisement is received from a new wireless hub (through a new AP), the end system sends a message to request registration to the registration server. The registration request is relayed from the new AP to the new wireless hub to the registration server.

When the registration server determines that the existing IWF can still be used, the registration server sends a build XTunnel Request message to request the existing IWF to build an XTunnel to the new wireless hub. Later, the registration server sends a tear down XTunnel request message to request the existing IWF to tear down the existing XTunnel with the old wireless hub. The build and tear XTunnel Request messages can be combined into one message. A foreign registration server does not forward the registration message to the home registration server since there is no change of IWF, either the serving IWF or home IWF.

Upon receiving a positive build XTunnel reply and a positive tear XTunnel reply from IWF, the registration server sends a registration reply to end system. As the registration reply reaches the new wireless hub, the connection table at the new wireless hub is updated to reflect the connection to the new AP. The new AP updates its MAC filter address table and connection table after receiving a message from the new wireless hub, and the registration reply is forwarded to the end system.

The registration server sends a release message to the old wireless hub. When the old wireless hub receives the release message, it updates its connection table and the MAC filter address table and connection table of the old AP.

As depicted in FIG. **35**, the macro mobility handoff case handles movement between wireless hubs that involves a change of the serving IWF in the foreign network, but it does not involve a change in the registration server. When an advertisement is received from a new wireless hub (through a new AP), the end system sends a message to request a network layer registration to the registration server. The registration request is relayed from the new AP to the new wireless hub to the registration server.

The registration server recognizes that it is a foreign registration server when the end system does not belong to the present registration server's network. This foreign registration server determines the identity of the home registration server by using a request, preferably a Radius Access request (RA request), to the foreign directory server (like a big yellow pages) and then assigns an appropriate IWF to be the serving IWF, and it forwards a registration request to the home registration server, preferably through a Radius Access request (RA request), informing the home registration server of the newly selected IWF.

The home registration server authenticates the registration request by using a request, preferably a Radius Access request (RA request), to the home directory server. Upon authenticating the request and determining that the existing home IWF can still be used, the home registration server instructs the home IWF to build a new I-XTunnel to the newly assigned serving IWF and to tear down the existing I-XTunnel to the old serving IWF. Upon receiving a positive build I-XTunnel reply and a positive tear I-XTunnel reply from the home IWF, the home registration server sends a registration reply to the foreign registration server.

The foreign registration server then instructs the newly assigned IWF to build an XTunnel to the new wireless hub. Upon receiving a positive build XTunnel reply, the foreign registration server instructs the old IWF to tear down the XTunnel to the old wireless hub. Upon receiving a positive build XTunnel reply and a positive tear XTunnel reply, the foreign registration server sends a registration reply to end system.

As the registration reply reaches the new wireless hub, the connection table at the new wireless hub is updated to reflect the connection to the new AP. The new AP updates its MAC filter address table and connection table after receiving a message from the new wireless hub, and the registration reply is forwarded to the end system.

The registration server sends a release message to the old wireless hub. When the old wireless hub receives the release message, it updates its connection table and the MAC filter address table, and the old AP updates its MAC filter address table and connection table after receiving a message from the old wireless hub.

The global mobility handoff case handles movement between wireless hubs that involves a change of registration servers. FIG. **36** depicts a global mobility handoff where the home IWF does not change, and FIG. **37** depicts a global mobility handoff where the home IWF changes. When an advertisement is received from a new wireless hub (through a new AP) in a new foreign network, the end system sends a message to request a network layer registration to the new foreign registration server. The registration request is relayed from the new AP to the new wireless hub to the new foreign registration server.

The registration server recognizes that it is a new foreign registration server when the end system does not belong to the present registration server's network. This foreign registration server determines the identity of the home registration server by using a request, preferably a Radius Access request (RA request), to the foreign directory server (like a big yellow pages) and then assigns an appropriate IWF to be the serving IWF, and it forwards the registration request to the home registration server, preferably through a Radius Access request (RA request), informing the home registration server of the newly selected IWF.

The home registration server authenticates the registration request by using a request, preferably a Radius Access request (RA request), to the home directory server. Upon authenticating the request and determining that the existing home IWF can still be used (FIG. **36**), the home registration server instructs the home IWF to build a new I-XTunnel to the serving IWF newly assigned by the new foreign registration server. The home registration server also sends a de-registration message to the old foreign registration server and instructs the home IWF to tear down the existing I-XTunnel to the existing serving IWF of the old foreign network. Upon receiving a positive build I-XTunnel reply and a positive tear I-XTunnel reply from the home IWF, the home registration server sends a registration reply to the new foreign registration server.

The new foreign registration server then instructs the newly assigned IWF to build an XTunnel to the new wireless hub. Upon receiving a positive build XTunnel reply, the foreign registration server sends a registration reply to end system. As the registration reply reaches the new wireless hub, the connection table at the new wireless hub is updated to reflect the connection to the new AP. The new AP updates its MAC filter address table and connection table after receiving a message from the new wireless hub, and the registration reply is forwarded to the end system.

The old foreign registration server instructs the old IWF to tear down the XTunnel to the old wireless hub. Upon receiving a positive tear XTunnel reply or contemporaneously with the tear down XTunnel request, the old foreign registration server sends a release message to the old wireless hub. When the old wireless hub receives the release message, it updates its connection table and the MAC filter address table, and the old AP updates its MAC filter address table and connection table after receiving a message from the old wireless hub.

Alternatively, after the home registration server authenticates the registration request from the new foreign registration server and determines that the existing home IWF cannot be used (FIG. **37**), the home registration server chooses a new home IWF and instructs the new home IWF to build a new level **2** tunnel protocol tunnel (L2TP tunnel) to the present PPP server (e.g., the PPP server in a connected ISP intranet). Then, the home registration server instructs the old home IWF to transfer its L2TP tunnel traffic to the new home IWF.

Then the home registration server instructs the new home IWF to build a new I-XTunnel to the serving IWF newly assigned by the new foreign registration server. The home registration server also sends a de-registration message to the old foreign registration server and instructs the home IWF to tear down the existing I-XTunnel to the existing serving IWF of the old foreign network. Upon receiving a positive build I-XTunnel reply and a positive tear I-XTunnel reply from the home IWF, the home registration server sends a registration reply to the new foreign registration server.

The new foreign registration server then instructs the newly assigned IWF to build an XTunnel to the new wireless hub. Upon receiving a positive build XTunnel reply, the

foreign registration server sends a registration reply to end system. As the registration reply reaches the new wireless hub, the connection table at the new wireless hub is updated to reflect the connection to the new AP. The new AP updates its MAC filter address table and connection table after receiving a message from the new wireless hub, and the registration reply is forwarded to the end system.

The old foreign registration server instructs the old IWF to tear down the XTunnel to the old wireless hub. Upon receiving a positive tear XTunnel reply or contemporaneously with the tear down XTunnel request, the old foreign registration server sends a release message to the old wireless hub. When the old wireless hub receives the release message, it updates its connection table and the MAC filter address table, and the old AP updates its MAC filter address table and connection table after receiving a message from the old wireless hub.

End systems constructed according to the present system interoperate with networks constructed according to the proposed IETF Mobile-IP standards, and end systems constructed according to the proposed IETF Mobile-IP standards interoperate with networks constructed according to the present invention.

Differences between the present system and the IETF Mobile-IP (RFC2002, a standards document) include:

(i) The present systemists a hierarchical concept for mobility management rather than a flat structure as in the proposed IETF Mobile-IP standard. Small mobility within a small area does not result in a network level registration. Micro mobility involves setting up of a new Xtunnel and tearing down of an existing Xtunnel. Global mobility, at the minimum, involves setting up of a new I-XTunnel and tearing down of an existing I-Xtunnel apart from the setting up/tearing down of XTunnel. Global mobility sometimes also involves setting up a new L2TP Tunnel and transferring of L2TP state from the existing L2TP Tunnel to the new L2TP Tunnel.

(ii) In the present invention, a user name plus a realm is used to identify a remote dial-up user rather than a fixed home address as in the case of the proposed IETF Mobile-IP standard.

(iii) In the present invention, registration and routing functions are carried out by separate entities. The two functions are carried out by the home agent in the proposed IETF Mobile IP standard, and both functions are carried out by the foreign agent in the proposed IEFT Mobile IP standard. In contrast, in an embodiment of the present invention, registration is carried out in the registration server and routing functions are carried out by both the home and foreign IWF and the wireless hub (also referred to as the access hub).

(iv) The present system utilizes three tunnels per PPP session. The XTunnel is more of a link-layer tunnel between the wireless hub and the serving IWF. The I-XTunnel between the serving IWF and the home IWF is more like the tunnel between home and foreign agents in the proposed IETF Mobile-IP standard. But it also has additional capabilities beyond the tunnels proposed by the Mobile-IP standard. The L2TP tunnel is used only when home IWF is not a PPP server. The number of these tunnels may be reduced by combining some functions in the same nodes as described earlier.

(v) In the present invention, wireless registration occurs before PPP session starts while in the proposed IETF Mobile-IP standard, Mobile-IP registration occurs after PPP session enters into the open state.

(vi) In the present invention, the network entity that advertises the agent advertisement (i.e., the wireless hub) is not on a direct link to the end systems whereas for the proposed IETF Mobile-IP standard, the agent advertisement must have a TTL of 1 which means that the end systems have a direct link with the foreign agent. In addition, the agent advertisement in the present systems not an extension to the ICMP router advertisements as in the proposed IETF Mobile-IP standard.

End systems in the present invention, should support agent solicitation. When an end system in the present system visits a network which is supporting the proposed IETF Mobile-IP standard, it waits until it hears an agent advertisement. If it does not receive an agent advertisement within a reasonable time frame, it broadcasts an agent solicitation.

In the present invention, network operators may negotiate with other networks that support the proposed IETF Mobile-IP standard such that home addresses can be assigned to the end systems of the present system that wish to use other networks. When the end system of the present system receives the agent advertisement, it can determine that the network it is visiting is not an a network according to the present system and hence uses the assigned home address to register.

For networks supporting the proposed IETF Mobile-IP standard, the PPP session starts before Mobile-IP registration, and the PPP server is assumed to be collocated with the foreign agent in such networks. In one embodiment, an SNAP header is used to encapsulate PPP frames in the MAC frames of the present system(in a manner similar to Ethernet format), and the foreign agent interprets this format as a proprietary PPP format over Ethernet encapsulation. Thus, the end system of the present system and its PPP peer can enter into an open state before the foreign agent starts transmitting an agent advertisement, and the end system of the present system can register.

To allow end systems supporting the proposed IETF Mobile-IP standard to work in networks of the type of the present invention, such mobiles are at least capable of performing similar MAC layer registrations. By making the agent advertisement message format similar to the proposed Mobile-IP standard agent advertisement message format, a visiting end system can interpret the agent advertisement and register with a wireless hub. In the present invention, registration request and reply messages are similar to the proposed IETF Mobile-IP standard registration request and reply messages (without any unnecessary extensions) so that the rest of the mobility management features of the present system are transparent to the visiting end systems.

Since end systems supporting the proposed IETF Mobile-IP standard expect a PPP session to start before Mobile-IP registration, an optional feature in wireless hubs of the present system starts to interpret PPP LCP, NCP packets after MAC-layer registrations.

To avoid losing traffic during handoffs, the mobility management of the present systemists the make before break concept. For local mobility, a make before break connection is achieved by turning the MAC-layer registration message relayed by the new AP to the wireless hub into a broadcast message. That way, the old AP can hear about the new registration and forward packets destined for the end system that have not been transmitted to the new AP.

For micro mobility, information about the new wireless hub is included in the Tear XTunnel message exchanged between the serving IWF and the old WH. That way, the old wireless hub can forward buffered packets to the new

wireless hub upon hearing a TearXTunnel message from the serving IWF. Alternatively, the RLP layer at the IWF knows the sequence number that has been acknowledged by the old wireless hub so far.

At the same time, the IWF knows the current send sequence number of the latest packet sent to the old wireless hub. Therefore, the IWF can forward those packets that are ordered in between these two numbers to the new wireless hub before sending newer packets to the new wireless hub. The RLP layer is assumed to be able to filter duplicate packet. The second approach is probably preferable to the first approach for the old wireless hub may not be able to communicate with one another directly.

For macro mobility, the old serving IWF can forward packets to the new serving IWF, in addition to the packet forwarding done from the old wireless hub to the new wireless. All we need to do is to forward the new serving IWF identity to the new serving IWF in the tear down I-XTunnel message. Another way to achieve the same result is to let the home IWF forward the missing packets to the new serving IWF rather than asking the old serving IWF to do the job since the home IWF knows the I-XTunnel sequence number last acknowledged by the old serving IWF and the current I-XTunnel sequence number sent by the home IWF.

The method of estimating how much buffer should be allocated per mobile per AP per wireless hub per IWF such that the traffic loss between handoffs can be minimized is to let the end system for the AP for the wireless hub for the IWF estimate the packet arrival rate and the handoff time. This information is passed to the old AP of the wireless hub of the IWF to determine how much traffic should be transferred to the new AP of the wireless hub of the IWF, respectively, upon handoffs.

To achieve route optimization in the present invention, the end system chooses the PPP server closest to the serving IWF. Without route optimization, excessive transport delays and physical line usage may be experienced.

For example, an end system subscribed to a home network in New York City may roam to Hong Kong. To establish a link to a Hong Kong ISP, the end system would have a serving IWF established in a wireless hub in Hong Kong and a home IWF established in the home network in New York City. A message would then be routed from the end system (roamed to Hong Kong) through the serving IWF (in Hong Kong) and through the home IWF (in New York City) and back to the Hong Kong ISP.

A preferred approach is to connect from the serving IWF (in Hong Kong) directly to the Hong Kong ISP. The serving IWF acts like the home IWF. In this embodiment, roaming agreements exist between the home and foreign wireless providers. In addition, the various accounting/billing systems communicate with one another automatically such that billing information is shared. Accounting and billing information exchange may be implemented using standards such as the standard proposed by the ROAMOPS working group of the IETF.

However, the serving IWF must still discover the closest PPP server (e.g., the Hong Kong ISP). In the present embodiment, the foreign registration server learns of the end system's desire to connect to a PPP server (e.g., a Hong Kong ISP) when it receives a registration request from the end system. When the foreign registration server determines that the serving IWF is closer to the desired PPP server (e.g., the Hong Kong ISP) than the home IWF is, the foreign registration server instructs the serving IWF to establish an L2TP tunnel to its nearest PPP server (in contrast to the PPP server closest to the home registration server and home IWF). Then, the foreign registration server informs the home registration server that the end system is being served by the serving IWF and the foreign PPP.

In an alternative embodiment, the foreign registration server determines that the serving IWF is closer to the desired PPP server (e.g., the Hong Kong ISP) than the home IWF is, when it receives a registration request from the end system. The foreign registration server relays the registration request message to the home registration server with an attached message indicating the serving IWF information and a notification that route optimization is preferred. At the same time, the foreign registration server instructs the serving IWF to establish an L2TP tunnel to the PPP server. Upon approving the registration request, the home registration server instructs the home IWF to transfer the L2TP state to the foreign IWF.

Having described preferred embodiments of a novel network architecture with wireless end users able to roam (which are intended to be illustrative and not limiting), it is noted that modifications and variations can be made by persons skilled in the art in light of the above teachings. For example, connection links described herein may make reference to known connection protocols (e.g., IP, TCP/IP, L2TP, IEEE 802.3, etc.); however, the system contemplates other connection protocols in the connections links that provide the same or similar data delivery capabilities. Acting agents in the above described embodiments may be in the form of software controlled processors or may be other form of controls (e.g., programmable logic arrays, etc.). Acting agents may be grouped as described above or grouped otherwise in keeping with the connection teachings described herein and subject to security and authentication teachings as described herein. Furthermore, a single access point, access hub (i.e., wireless hub) or inter-working function unit (IWF unit) may provide multi-channel capability. Thus, a single access point or access hub or IWF unit may act on traffic from multiple end systems, and what is described herein as separate access points, access hubs or IWF units contemplates equivalence with a single multi-channel access point, access hub or IWF unit. It is therefore to be understood that changes may be made in the particular embodiments of the system disclosed which are within the scope and spirit of the systems defined by the appended claims.

Having thus described the system with the details and particularity required by the patent laws, what is claimed and desired protected by letters patent is set forth in the appended claims:

What is claimed is:

1. A coupled data network comprising:

a foreign network that includes a foreign mobile switching center and a base station, the base station including an access hub with a serving inter-working functions;

a home network that includes a home mobile switching center, the home mobile switching center including plural home inter-working functions, one of which collects accounting data for billing purposes; and

a roaming end system subscribed to the home network and operating within the foreign network, a message being transportable between the roaming end system and the home inter-working functions through the serving inter-working functions using a protocol that ensures in sequence delivery of data packets.

2. The network of claim 1, wherein

the foreign mobile switching center includes a serving registration server, and the access hub including a proxy registration agent,

the home mobile switching center includes a home registration server, and

the roaming end system including an end registration agent, the end registration agent being coupled to the proxy registration agent, the proxy registration agent being coupled to the serving registration server, the serving registration server being coupled to the home registration server.

3. The network of claim 2, wherein the home registration server includes a module to authenticate that the foreign network is authorized to host the roaming end system.

4. The network of claim 2, wherein the home registration server includes a module to authenticate that the roaming end system is authorized to receive services of the home network.

5. The network of claim 2, wherein the serving registration server includes a module to authenticate that the roaming end system is a subscriber of the home network.

6. The network of claim 2, wherein:

the home registration server includes a module to authenticate that the foreign network is authorized to host the roaming end system;

the home registration server includes a module to authenticate that the roaming end system is authorized to receive services of the home network; and

the serving registration server includes a module to authenticate that the roaming end system is a subscriber of the home network.

7. The network of claim 1, wherein

the foreign mobile switching center includes a serving registration server,

the home mobile switching center includes a plurality of unassigned home inter-working functions; and

the roaming end system including an end registration agent to form a registration request, the end registration agent sending the registration request through the serving registration server to the home registration server, the home registration server including a module to select an active home inter-working function from the plurality of unassigned home inter-working functions based on the registration request.

8. The network of claim 7, wherein:

the serving inter-working function is regarded as an active serving inter-working function;

the foreign network further includes a plurality of serving inter-working functions; and

the serving registration server includes a module to select the active serving inter-working function from the plurality of serving inter-working functions based on the registration request.

9. The network of claim 7, wherein the home registration server includes a module to authenticate that the foreign network is authorized to host the roaming end system.

10. The network of claim 7, wherein the home registration server includes a module to authenticate that the roaming end system is authorized to receive services of the home network.

11. The network of claim 7, wherein the serving registration server includes a module to authenticate that the roaming end system is a subscriber of the home network.

12. The network of claim 7, wherein:

the registration request includes service type information; and

the home registration server includes a module to control the selection of the active home inter-working function based on the service type information.

13. The network of claim 12, wherein the service type information specifies a request for one of public internet service and private intranet service.

14. The network of claim 12, wherein the service type information specifies a request for one of mobile service and fixed service.

15. The network of claim 7, wherein:

the registration request includes quality of service information; and

the home registration server includes a module to control the selection of the active home inter-working function based on the quality of service information.

16. The network of claim 15, wherein the quality of service information specifies a request for one of constant bit rate service, real time variable bit rate service, non-real time variable bit rate service, unspecified bit rate service and available bit rate service.

17. The network of claim 1, further comprising:

a second end system subscribed to the home network and operating as a fixed end system within the home network; and

a home base station that includes a home access hub with a second home inter-working function, a second message being transportable between the second end system and a second communications server through the second home inter-working function.

18. The network of claim 1, further comprising:

a second end system subscribed to the home network and operating as a mobile end system within the home network;

a home mobile switching center having a second home inter-working function, the first home inter-working function being included in the home mobile switching center; and

a home base station that includes a home access hub with a second serving inter-working function, a second message being transportable between the second end system and a second communications server through the second serving inter-working function and through the second home inter-working function.

19. The network of claim 1, wherein the first home inter-working function includes a home accounting collection module to collect accounting data on message traffic transported through the first home inter-working function.

20. The network of claim 1, wherein:

the home network further includes a home mobile switching center that includes a home accounting server; and

the home accounting collection module includes a submodule to periodically send accounting reports to a home accounting server.

21. The network of claim 20, wherein:

the home network further includes a home billing processor; and

the home accounting server includes a module to send accounting reports to the home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the home accounting server.

22. The network of claim 21, wherein:

the foreign network further includes a foreign accounting server and a foreign billing processor;

the first serving inter-working function includes a foreign accounting collection module to collect accounting data on message traffic transported through the first serving inter-working function, the foreign accounting

collection module including a sub-module to periodically send accounting reports to the foreign accounting server, the foreign accounting server including a module to send accounting reports to the foreign billing processor, the foreign billing processor including a module to send accounting reports to the home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the foreign billing processor.

23. The network of claim **1**, wherein:

the home network further includes a home billing processor;

the foreign network further includes a foreign accounting server and a foreign billing processor;

the first serving inter-working function includes a foreign accounting collection module to collect accounting data on message traffic transported through the first serving inter-working function, the foreign accounting collection module including a sub-module to periodically send accounting reports to the foreign accounting server, the foreign accounting server including a module to send accounting reports to the foreign billing processor, the foreign billing processor including a module to send accounting reports to the home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the foreign billing processor.

24. The network of claim **1**, wherein:

the foreign mobile switching center includes a foreign accounting server; and

the foreign accounting collection module includes a sub-module to periodically send accounting reports to the foreign accounting server.

25. The network of claim **1**, wherein:

the home mobile switching center includes a home accounting server;

a home accounting collection module in said home inter-working function includes a sub-module to periodically send accounting reports to the home accounting server.

26. The network of claim **25**, wherein:

the home network further includes a home billing processor; and

the home accounting server includes a module to send accounting reports to the home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the home accounting server.

27. The network of claim **1**, wherein:

the foreign network further includes a foreign accounting server and a foreign billing processor;

the foreign accounting collection module includes a sub-module to collect accounting data on message traffic transported through the first serving inter-working function, the foreign accounting collection module further including a sub-module to periodically send accounting reports to the foreign accounting server, the foreign accounting server including a module to send accounting reports to the foreign billing processor, the foreign billing processor including a module to send accounting reports to a home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the foreign billing processor.

28. The network of claim **1**, wherein:

the foreign mobile switching center includes a foreign accounting server;

the home mobile switching center includes a home accounting server;

the foreign accounting collection module includes a sub-module to periodically send accounting reports to a foreign accounting server; and

a home accounting collection module includes a sub-module to periodically send accounting reports to a home accounting server.

29. A wireless data network coupled to a foreign network that includes a foreign mobile switching center and a base station that includes an access hub with a serving inter-working function, the wireless data network comprising:

a home network that includes a home mobile switching center, the home mobile switching center including plural home inter-working functions, one of which collects accounting data for billing purposes; and

an end system subscribed to the home network and operating within the foreign network, a message being transportable between the end system and the home accounting function through the serving inter-working function using a protocol that ensures in sequence delivery of data packets.

30. The network of claim **29**, wherein the foreign mobile switching center including a serving registration server, and the access hub including a proxy registration agent, the data network comprising:

the home mobile switching center includes a home registration server;

the end system including an end registration agent, the end registration agent being coupled to the proxy registration agent, the proxy registration agent being coupled to the serving registration server, the serving registration server being coupled to the home registration server.

31. The network of claim **30**, wherein the home registration server includes a module to authenticate that the foreign network is authorized to host the end system.

32. The network of claim **30**, wherein the home registration server includes a module to authenticate that the end system is authorized to receive services of the home network.

33. The network of claim **29**, wherein the foreign mobile switching center includes a serving registration server,

the home mobile switching center includes a home registration server and a plurality of unassigned home inter-working functions, and

the end system including an end registration agent to form a registration request, the end registration agent sending the registration request through the serving registration server to the home registration server, the home registration server including a module to select an active home inter-working function from the plurality of unassigned home inter-working functions based on the registration request.

34. The network of claim **33**, wherein the home registration server includes a module to authenticate that the foreign network is authorized to host the end system.

35. The network of claim **33**, wherein the home registration server includes a module to authenticate that the end system is authorized to receive services of the home network.

36. The network of claim **33**, wherein:

the registration request includes service type information; and

the home registration server includes a module to control the selection of the active home inter-working function based on the service type information.

37. The network of claim **36**, wherein the service type information specifies a request for one of public internet service and private intranet service.

38. The network of claim **36**, wherein the service type information specifies a request for one of mobile service and fixed service.

39. The network of claim **33**, wherein:

the registration request includes quality of service information; and

the home registration server includes a module to control the selection of the active home inter-working function based on the quality of service information.

40. The network of claim **39**, wherein the quality of service information specifies a request for one of constant bit rate service, real time variable bit rate service, non-real time variable bit rate service, unspecified bit rate service and available bit rate service.

41. The network of claim **29**, further comprising:

a second end system subscribed to the home network and operating as a fixed end system within the home network; and

a home base station that includes a home access hub with a second home inter-working function, a second message being transportable between the second end system and a second communications server through the second home inter-working function.

42. The network of claim **29**, further comprising:

a second end system subscribed to the home network and operating as a mobile end system within the home network;

the home mobile switching center having a second home inter-working function, and

a home base station that includes a home access hub with a second serving inter-working function, a second message being transportable between the second end system and a second communications server through the second serving inter-working function and through the second home inter-working function.

43. The network of claim **29**, wherein the first home inter-working function includes a home accounting collection module to collect accounting data on message traffic transported through the first home inter-working function.

44. The network of claim **29**, wherein:

the home mobile switching center includes a home accounting server; and

the home accounting collection module includes a sub-module to periodically send accounting reports to a home accounting server.

45. The network of claim **44**, wherein:

the home network further includes a billing processor; and

the home accounting server includes a module to send accounting reports to the billing processor, the billing processor including a module to prepare customer bills based on the accounting reports from the home accounting server.

46. The network of claim **45**, wherein:

the foreign network further includes a foreign accounting server and a foreign billing processor;

the first serving inter-working function includes a foreign accounting collection module to collect accounting data on message traffic transported through the first serving inter-working function, the foreign accounting collection module including a sub-module to periodically send accounting reports to the foreign accounting server, the foreign accounting server including a module to send accounting reports to the foreign billing processor, the foreign billing processor including a module to send accounting reports to the home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the foreign billing processor.

47. The network of claim **29**, wherein:

the home network further includes a home billing processor;

the foreign network further includes a foreign accounting server and a foreign billing processor;

the first serving inter-working function includes a foreign accounting collection module to collect accounting data on message traffic transported through the first serving inter-working function, the foreign accounting collection module including a sub-module to periodically send accounting reports to the foreign accounting server, the foreign accounting server including a module to send accounting reports to the foreign billing processor, the foreign billing processor including a module to send accounting reports to the home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the foreign billing processor.

48. The network of claim **28**, wherein:

the home mobile switching center includes a home accounting server;

a home accounting collection module in a home inter-working function includes a sub-module to periodically send accounting reports to the home accounting server.

49. The network of claim **48**, wherein:

the home network further includes a home billing processor; and

the home accounting server includes a module to send accounting reports to the home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the home accounting server.

50. The network of claim **29**, wherein:

the foreign network further includes a foreign accounting server and a foreign billing processor;

the foreign accounting collection module includes a sub-module to collect accounting data on message traffic transported through the first serving inter-working function, the foreign accounting collection module further including a sub-module to periodically send accounting reports to the foreign accounting server, the foreign accounting server including a module to send accounting reports to the foreign billing processor, the foreign billing processor including a module to send accounting reports to a home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the foreign billing processor.

51. The network of claim **29**, wherein:

the foreign mobile switching center includes a foreign accounting server;

the home mobile switching center includes a home accounting server;

the foreign accounting collection module includes a sub-module to periodically send accounting reports to a foreign accounting server; and

a home accounting collection module includes a sub-module to periodically send accounting reports to a home accounting server.

52. A home network for use in a coupled data network coupled to a foreign network that includes a foreign mobile switching center, which includes a serving hub with serving inter-working function and a proxy registration agent, and a roaming end system which is subscribed to the home network and operating within the foreign network, said roaming end system including an end registration agent, comprising:

a home mobile switching center including plural home inter-working functions, one of which collects accounting data for billing purposes and a home registration server;

wherein a message being transportable between the roaming end system and the home inter-working functions through the serving inter-working function using a protocol that ensures in sequence delivery of data packets

and the end registration agent being coupled to the proxy registration agent, the proxy registration agent being coupled to the serving registration server, the serving registration server being coupled to the home registration server.

53. The network of claim 52, wherein the home registration server includes a module to authenticate that the foreign network is authorized to host the roaming end system.

54. The network of claim 52, wherein the home registration server includes a module to authenticate that the roaming end system is authorized to receive services of the home network.

55. The network of claim 52, wherein:

the home registration server includes a module to authenticate that the foreign network is authorized to host the roaming end system;

the home registration server includes a module to authenticate that the roaming end system is authorized to receive services of the home network; and

wherein the serving registration server includes a module to authenticate that the roaming end system is a subscriber of the home network.

56. A roaming end system for use in a coupled data network coupled to a foreign network, that includes a foreign mobile switching center, which includes a serving hub with a serving inter-working function and a proxy registration agent, and a home network that includes a home mobile switching center including a home inter-working function and a home registration server, comprising:

the roaming end system subscribed to the home network and operating within the foreign network, a message being transportable between the roaming end system and the home inter-working function through the serving inter-working function using a protocol that ensures in sequence delivery of data packets.

57. A coupled data network comprising:

a foreign network that includes a foreign mobile switching center and a base station, the base station including an access hub with a serving inter-working function;

a home network that includes a home mobile switching center, the home mobile switching center including a home inter-working function;

a roaming end system subscribed to the home network and operating within the foreign network, a message being transportable between the roaming end system and the home inter-working function through the serving inter-working function using a protocol that ensures in sequence delivery of data packets; and

wherein the first home inter-working function includes a home accounting collection module to collect accounting data on message traffic transported through the first home inter-working function.

58. A wireless data network coupled to a foreign network that includes a foreign mobile switching center and a base station that includes an access hub with a serving inter-working function, the wireless data network comprising:

a home network that includes a home mobile switching center, the home mobile switching center including home inter-working function;

an end system subscribed to the home network and operating within the foreign network, a message being transportable between the end system and the home inter-working functions through the serving inter-working function using a protocol that ensures in sequence delivery of data packets; and

wherein the first home inter-working function includes a home accounting collection module to collect accounting data on message traffic transported through the first home inter-working function.

59. A wireless data network coupled to a foreign network that includes a foreign mobile switching center and a base station that includes an access hub with a serving inter-working function, the wireless data network comprising:

a home network that includes a home mobile switching center, the home mobile switching center including home inter-working function;

an end system subscribed to the home network and operating within the foreign network, a message being transportable between the end system and the home inter-working functions through the serving inter-working function using a protocol that ensures in sequence delivery of data packets; and

wherein:

the foreign network further includes a foreign accounting server and a foreign billing processor;

the foreign accounting collection module includes a sub-module to collect accounting data on message traffic transported through the first serving inter-working function, the foreign accounting collection module further including a sub module to periodically send accounting reports to the foreign accounting server, the foreign accounting server including a module to send accounting reports to the foreign billing processor, the foreign billing processor including a module to send accounting reports to a home billing processor, the home billing processor including a module to prepare customer bills based on the accounting reports from the foreign billing processor.

60. A wireless data network coupled to a foreign network that includes a foreign mobile switching center and a base station that includes an access hub with a serving inter-working function, the wireless data network comprising:

a home network that includes a home mobile switching center, the home mobile switching center including home inter-working function;

an end system subscribed to the home network and operating within the foreign network, a message being transportable between the end system and the home inter-working functions through the serving inter-working function using a protocol that ensures in sequence delivery of data packets; and

wherein:

the foreign mobile switching center includes a foreign accounting server;

the home mobile switching center includes a home accounting server;

the foreign accounting collection module includes a sub-module to periodically send accounting reports to a foreign accounting server; and

a home collection module includes a sub-module to periodically send accounting reports to a home accounting server.

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